Edge deterioration on local roads

by P Watson, A Wright and S McRobbie (TRL Limited)

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Executive Summary

Project Title: Edge Deterioration on Local Roads

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

Project Manager: Dr A Wright, Transport Research Laboratory

The Department for Transport (DfT) intends to require traffic speed surveys of pavement condition over the majority of the local road network, using the SCANNER (Surface Condition Assessment of the National Network of Roads) specification. To obtain best value from these surveys it has been recognised that there is a need to undertake developments in the methods employed to process the SCANNER data, to identify defects and determine condition. The DfT has therefore commissioned projects to undertake developments in SCANNER crack detection, detection of other visible defects, uses of surface texture measurements, use of road shape data, use of road geometry data and the measurement of edge condition.

The report describes the work carried out to develop methods to detect deterioration of the road edge. The overall objectives of this project were:

- To identify the aspects of the edge condition of local road carriageways that are relevant to road user requirements, road service level and maintenance requirements.

- To develop automatic techniques or methods for measuring and recording the key aspects of the edge condition, deterioration and defects, suitable for incorporation in an overall assessment of road condition and maintenance need.

- To provide workable specifications and assessment techniques for the methods or techniques so that they may be implemented in surveys in 2007.

At the beginning of the project, a consultation and review was carried out, including discussions with a number of local authorities and consultants to assess their views on a range of issues relating to the collection of SCANNER data. The review found that engineers have a basic requirement for a measure which indicates the presence of edge deterioration along a length of road. Although more detailed information is desirable, this is not essential. However, the consultation noted that the key edge defect of interest was potholes at the road edge. A further area of interest for those consulted was the provision of spatial information regarding the edge defects – i.e. how far the defects extend over the width of the road.

Methods for the basic reporting on edge deterioration have been proposed in previous research undertaken by TRL for the DfT, which have been referred to as the Initial Parameters. This research has carried out an assessment of the Initial Parameters for identifying edge deterioration to determine if they are successful in providing a basic measure of edge deterioration. A second area of this work has considered the development of more sophisticated methods to identify edge deterioration, to enable the identification of the key defects identified in the consultation, including overriding and potholes at the road edge, and the extent to which this deterioration exists over the width of the road.

Surveys were undertaken on a range of network sites located on the local road network, covering A, B, C and Unclassified roads, using the Highways Agency’s HARRIS1 and HARRIS2 survey vehicles, to obtain test data for the development work. Transverse profile data from HARRIS1 was used for testing and improving the Initial Parameters, and the enhanced capabilities of HARRIS2 have been used in the development of enhanced methods for detecting edge deterioration. The report describes the development and assessment of both approaches in detail, and assesses results obtained using both methods against reference data consisting of CVI data and manual analysis of video, image and transverse profiles.
For the development and assessment of the Initial Parameters there are a number of conclusions and recommendations:

- The assessment of the Initial Parameters that relate to edge deterioration has shown good agreement with the reference data. Where differences occurred, these were often at a level similar to the differences observed between the reference datasets. However, the coverage achieved in delivery of the Initial Parameters is quite low, and there is a significant level of noise present in the Initial Parameter values, and it may be beneficial to aggregate the Parameters over longer lengths.

- Assessment of the Initial Parameters that relate to transverse deformation has shown that cleaned rut depths are comparable to standard rut depths. However, the cleaned rut depths often benefit from reporting lower levels than standard rut depths due to the removal of kerbs and verge features from the profile. Nevertheless, unexpected high levels of cleaned rut depths were observed on certain sites, particularly on very narrow rural roads. The transverse profile deformation parameter ‘ADFD’ has been observed to successfully identify the presence of both rutting and non-rutting transverse deformation.

As a result of the above observations, enhancements to the methods for calculating the Initial Parameters have been developed and tested. These are aimed at improving the accuracy and coverage of the Parameters, and to increase reliability on narrow roads.

Following a review of the behaviour of the Initial Parameters at the network level, an Edge Deterioration Indicator has been proposed, which combines individual values of the Initial Parameters to give a single value over each reporting interval. Threshold values for the Indicator have been recommended that report the edge condition over three levels of severity. Assessment of the Indicator has shown reasonable agreement with the opinions of engineers, although some differences were observed. The overall trends in the levels reported by the Edge Deterioration Indicator within different road classes show good agreement with the trends reported by the CVI survey.

In the development of enhanced methods to identify edge deterioration, the work has proposed an approach to identify the location of the road edge, report overriding, edge stepping, and pothole/deformation, and to identify if a verge or a kerb is present. These methods are based on the use of colour images and detailed transverse profile measurements, and have been derived from earlier work carried out by TRL for TRF.

It has been found that, in general, the enhanced methods enable us to locate the road edge to a much higher level of accuracy than that achieved by the Initial methods. This edge location is used in the identification of overriding and rutting of the verge, which are reported to a reasonable level of accuracy. Although a number of overridden lengths are missed when applying the enhanced methods, the number of false positives was low. Furthermore, significant stepping at the road edge is identified at a higher level of accuracy than by the Initial Parameters. A high level of accuracy was also obtained in the identification of surfaced or paved verges, and this can be used to increase the accuracy in the reporting of overriding.

The enhanced methods have been applied to the identification of potholes and severe transverse deformation. However, the reporting of potholes did not always agree with the reference, possibly because of differences in the way the defects are identified. The enhanced methods were also unable to accurately detect all raised kerbs, however it was found that the output can be used to provide an indication of whether a particular length is generally kerbed.

The report reviews the implications of the work and makes recommendations regarding the introduction of the Edge Deterioration Indicator based on the improved Initial Parameters, and suggests possibilities for the phased introduction of the enhanced methods, with consideration to the equipment required, processing needs and the delivery and use of the data.
1 Introduction

The UK Roads Board intends to carry out traffic speed surveys of pavement condition over the majority of the local road network, under the SCANNER (Surface Condition Assessment of the National NEtwork of Roads) project. In order for these surveys to be successful, there are a number of areas of pavement assessment that require further development. One of these areas is the detection of road edge deterioration, which to date, has only been performed in manual surveys. This report describes research carried out to measure and assess road edge deterioration. The research has had the aim of developing techniques to allow machine based automatic surveys to detect and report edge deterioration, and provide guidance on any maintenance required.

This work forms part of the second stage of research carried out for the DfT to identify defects in road pavements at traffic speed. The first stage of this work, carried out in 2004, investigated the possibilities of detecting both edge deterioration and transverse profile defects using existing traffic speed survey equipment. The methods developed, reported by Watson et al. (2004) and Nesnas et al. (2004), did not require the implementation of new measurement technologies on the current vehicles.

Development of these methods, to produce measurements which are referred to here as the Initial Parameters, included limited testing only. This was sufficient to suggest that the parameters would provide a viable measure of the condition of the road edge and transverse profile. Further work, presented in this report, has sought to undertake more comprehensive testing of these methods using a larger range of sites than used in the development stage. This testing has been performed using a greater length of data, encompassing a greater range of road types and using additional sources of reference data, enabling a more accurate assessment of their performance. Hence this assessment, carried out in parallel with the implementation of the methods for network surveys by survey contractors, has enabled the performance of the Initial Parameters to be confirmed, determined the needs for improvement, and assessed the performance of these improvements.

The work also considers how the Initial Parameters should be used by engineers for condition assessment. By assessing the performance of the Initial Parameters on a wide range of sites, this work has sought to develop threshold values for the identification of sites, and hence develop a single numerical measure to indicate the level of deterioration.

As the Initial Parameters are based purely on measurements provided by existing survey techniques, they draw on less information than could potentially be provided by more sophisticated methods, for example methods to provide higher resolution transverse profile data. Although the Initial Parameters show promise, their accuracy and coverage will inevitably be affected by the limitations of the data on which they rely. Therefore, in the second part of this work we investigate enhanced methods for identifying edge deterioration, that use state of the art road measurement technology currently not in routine use on the network, with the aim of determining whether such technology is capable of providing a significant increase in performance. The key aims of the research using the enhanced measurements were:

- to develop methods to identify edge deterioration defects and to indicate the overall edge condition;
- to establish whether these new methods allow the identification of more edge defects than the existing methods;
- to identify whether the new methods are more accurate than existing methods.

It is anticipated that the results arising from this second stage will inform decisions regarding the level of investment required by the industry in enhanced data collection technology.
2 Consultation and review

At the initiation of this project a consultation and review phase was undertaken. Within the consultation, discussions were held with a number of local authorities and consultants to assess their views on a range of issues relating to the collection of SCANNER data. The results were presented in an interim report (Parsley et al., 2005). However, for completeness Appendix A summarises the results of this consultation, in relation to the work on edge deterioration. The consultation and review carried out for this project built upon initial work carried out prior to the introduction of SCANNER surveys (McRobbie and Wright, 2004).

The initial consultation and review found that local authority engineers would not accept SCANNER surveys if they were unable to provide at least some measurement edge deterioration. Therefore a data analysis exercise was performed during the initial review, investigating the relationship between CVI reports of edge deterioration and existing TTS output parameters such as cracking, rutting and longitudinal profile variance. This aimed to find if any existing outputs could be used as a proxy for edge deterioration. This found no strong relationships between edge deterioration, as reported in CVI surveys, and existing TTS parameters. The review therefore concluded that new parameters would be required if edge deterioration was to be delivered using currently available measurement technology and equipment.

The initial review had found that most engineers had a basic requirement for a measure which indicated the presence of edge deterioration along a length of road. Additional information regarding the nature or severity of the deterioration was not considered essential (although would be desirable). Research was therefore undertaken to develop initial, basic, methods to identify the edge deterioration. This work lead to the Initial Parameters for the identification of transverse unevenness and edge deterioration. These could be calculated using the transverse profile data provided from the majority of the current survey vehicles. However, restricted testing of these parameters was carried out in the initial project.

The consultation and review carried out in this project has confirmed the conclusions of the initial work. In addition, the consultation noted that the key edge defect, in the opinion of the engineer, is potholes at the road edge. This is a defect that typically results from the presence of overriding with the development of a step at the road edge, followed by the deterioration of the road to form a pothole. This can be associated with the presence of cracking at the road edge. A further area of interest for those consulted was the ability to determine spatial information regarding the edge defects – i.e. how far do the defects extend over the width of the road.

It was therefore concluded that this research project should consider two areas of investigation. The first would carry out an assessment of the Initial Parameters for identifying edge deterioration. This would determine if the parameters are successful in providing a basic measure of edge deterioration, and investigate how this should be delivered. The second area would consider the development of more sophisticated methods to identify edge deterioration, that would hopefully enable the identification of the key defects identified in the consultation, including overriding, potholes at the road edge, and the extent to which this deterioration exists over the width of the road. It was also noted that, although edge cracking is also a defect of concern, the identification of cracking is seen to be a task linked to the development of existing crack assessment methods. Therefore the work would not seek to develop crack identification algorithms.
3 Data sources

3.1 Test routes

Test routes of approximately 200km in length were selected to evaluate the performance of the methods developed in the Initial Research projects, and to provide data for the development of enhanced techniques for detecting and quantifying edge deterioration. Routes were selected based on information provided by Hampshire, Shropshire, Leicestershire and Durham County Councils. Engineers in each local authority identified a number of sites within their networks where some aspect of the pavement condition was known to be poor. TRL then defined a series of test routes which enabled these locations, and parts of the network where no concerns had been expressed, to be surveyed in an efficient manner. Table 1 lists the test routes with a brief description, the types of machine survey carried out for each route and the reference data available from each test route.

<table>
<thead>
<tr>
<th>County</th>
<th>Route</th>
<th>Description</th>
<th>Length (km)</th>
<th>H1</th>
<th>H2</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hampshire</td>
<td>1</td>
<td>Blackwater -A30-Fleet-Feltham. Principal local town, suburban and rural main roads. Mix of A and B class roads.</td>
<td>18.3</td>
<td>✓</td>
<td>✓</td>
<td>C, L, V</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Liphook-Liss-A3-Petersfield Rural minor roads, small towns. Apart from A3 Dual Carriageway linking sections, route is a mix of B and C class.</td>
<td>42.3</td>
<td>✓</td>
<td>✓</td>
<td>C, L, V</td>
</tr>
<tr>
<td>Leicestershine</td>
<td>1</td>
<td>Hinckley Town centre and periphery, rural main roads (mostly A class). Mostly B class, some A and U class.</td>
<td>21.4</td>
<td>✓</td>
<td>✓</td>
<td>C, L</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Melton Mowbray Rural minor roads, small villages, town centre and periphery. C, B and A class roads.</td>
<td>25.7</td>
<td>✓</td>
<td>✓</td>
<td>C, L</td>
</tr>
<tr>
<td>Shropshire</td>
<td>1</td>
<td>Shrewsbury City centre, suburbs, trunk and industrial estate roads. Mostly A and B class, some C and U class.</td>
<td>19.2</td>
<td>✓</td>
<td>✓</td>
<td>S, L</td>
</tr>
<tr>
<td>Durham</td>
<td>1</td>
<td>B, C and U class roads in a very rural area.</td>
<td>25.1</td>
<td>✓</td>
<td></td>
<td>S, L</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Mostly A class roads with some B. Rural main roads between towns and motorway.</td>
<td>27.5</td>
<td>✓</td>
<td></td>
<td>S, L</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Urban city centre C class roads</td>
<td>2.4</td>
<td>✓</td>
<td></td>
<td>S, L</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Rural and urban A and B class roads, route is on edge of a small town.</td>
<td>15.2</td>
<td>✓</td>
<td></td>
<td>S, L</td>
</tr>
</tbody>
</table>

Type of reference data available, indicated for each site in the table:
- C – CVI
- S – Shape files showing pavement condition, derived from processed CVI data
- L – Local Authority engineers assessment (available for part of route only)
- V – HARRIS1 manual data analysis from forward facing video.

Types of machine surveys carried out:
- H1 – HARRIS1 survey for initial parameter assessment.
- H2 – HARRIS2 survey for enhanced methods research.

Table 1: Data available for each test route.

3.2 Data

Table 1 details the data sources available for use in this work. All routes were surveyed using the Highways Agency’s HARRIS1 vehicle. The Hampshire, Leicestershire and Shropshire routes were also surveyed with the Highways Agency’s HARRIS2 vehicle.
The HARRIS1 transverse profile data was used for the assessment of the Initial Parameters in Section 5. The colour images and detailed transverse profile data available from HARRIS2 were used for the development of enhanced methods, discussed in Section 8.

### 3.2.1 HARRIS1 and HARRIS2 survey data

HARRIS1 and HARRIS2 have different methodologies for making measurements of profile. Both systems are also capable of collecting images of the road surface.

HARRIS1 collects 25 measurements across the width of the vehicle. These measurements are made at a transverse spacing of 150mm, providing a profile 3.6m in width, with one such profile every 100mm along the road. These measurements are the basis for the calculation of the Initial Parameter values. (The HARRIS1 images were not required for the Initial Parameters.)

HARRIS2 uses a scanning profile laser which provides 1000 measurement points per transverse profile, measured at a longitudinal spacing of approximately 24mm. The profile produced using the scanning laser is nominally 4m in width, varying slightly with vehicle roll, and depending on the pavement surface shape. The HARRIS2 image system can collect downward facing colour images covering a width of nearly 4m. The image width extends over 1m past each side of the vehicle and will record the road edge and verge on most local authority single lane roads. The enhanced methods developed made use of these scanned profile measurements, as well as the imaging capabilities of HARRIS2.

### 3.3 Reference data

Manually collected CVI data was obtained from Hampshire and Leicestershire County Councils to provide reference data on these routes, to allow us to ‘benchmark’ against this existing condition assessment method. A second reference dataset for the Hampshire routes was obtained by undertaking a manual analysis of the HARRIS1 forward facing video footage. In addition, engineers from the local authorities supplying the data nominated, and assessed, a number of poor sites within each route. Further details of each of these data sources are given below.

#### 3.3.1 CVI data

CVI survey data was provided for the Hampshire and Leicestershire survey routes by the local authorities. The CVI data for the sections comprising each survey route were identified, extracted, ordered and aligned with the HARRIS1 and HARRIS2 survey data obtained on the sites. This allowed CVI values to be plotted alongside the parameters to be tested. For comparison of the SCANNER parameters relating to edge deterioration, the CVI outputs BLED and BRED were used. No manually assessed CVI rut data (BWTR) was available, as machine surveys had been used to make actual measurements of rut depths.

#### 3.3.2 Visual surveys from Manual Analysis of HARRIS1 forward video

A manual analysis was carried out of the forward facing video recorded during the HARRIS1 survey of Hampshire. This looked for the occurrence of a range of features relating to edge deterioration and recorded the chainages of the start and end of these features when they were visible on the video. This data was processed to give a length of each feature for each 10m of the survey. If any 10m subsection included 5m or more of defects, the 10m was counted towards the number of defective lengths within each 1km. This was recorded in terms of both edge roughness and overriding: If the manual analysis identified edge cracking, fretting, settlement or subsidence or potholes the 10m subsection contributed to the indicator of edge roughness; similarly this assessment was carried out for features relating to overriding (edge stepping and rutted verge).
3.3.3 Assessment by Local Authority Engineers

As described in Section 3.1 each of the participating Local Authorities was asked to supply details of sites in their network, which were known to be in poor condition for one reason or another. These sites were also used in the research on crack detection and the use of texture data, and so not all sites had transverse profile or edge defects present. This gave a set of sites which had a range of transverse profile and edge conditions ranging from sound to severely deteriorated. As well as identifying any particular site as being of concern the engineers were also asked to identify which of a list of defects were present on the site, and to rate how severe each defect was on a scale of 0-3, with 3 indicating the most severe level. These sites are listed in Table 2, with the engineer’s opinion of the severity of defects relevant to this work also shown, for edge deterioration defects and also for transverse profile defects (indicated in the table as shape/unevenness) which are examined in section 5.4.2.

<table>
<thead>
<tr>
<th>Site</th>
<th>Route</th>
<th>Environment, road class</th>
<th>Shape / unevenness</th>
<th>Edge defects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hampshire</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H1</td>
<td>North</td>
<td>Non-built-up, A</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>H2</td>
<td>South</td>
<td>Non-built-up, A</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>H3</td>
<td>South</td>
<td>Built-up, B</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>H4</td>
<td>South</td>
<td>Non-built-up, B</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>H5</td>
<td>South</td>
<td>Built-up, C</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>H6</td>
<td>South</td>
<td>Non-built-up, C</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Leicestershire</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L1</td>
<td>Route 1</td>
<td>Built-up, B</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>L2</td>
<td>Route 1</td>
<td>Built-up, B</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>L3</td>
<td>Route 2</td>
<td>Built-up, C</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>L4</td>
<td>Route 2</td>
<td>Built-up, unclassified</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Shropshire</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S1</td>
<td>Route 1</td>
<td>Built-up, A</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>S2</td>
<td>Route 1</td>
<td>Non-built-up, A</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>S3</td>
<td>Route 1</td>
<td>Non-built-up, A</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>S4</td>
<td>Route 1</td>
<td>Built-up, B</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>S5</td>
<td>Route 1</td>
<td>Built-up, B</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>S6</td>
<td>Route 1</td>
<td>Built-up, A</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>County Durham</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D1</td>
<td>Route 4</td>
<td>Non-built-up, A</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>D2</td>
<td>Route 4</td>
<td>Non-built-up, B</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>D3</td>
<td>Route 3</td>
<td>Built-up, C</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>D4</td>
<td>Route 3</td>
<td>Built-up, unclassified</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>D5</td>
<td>Route 2</td>
<td>Non-built-up, A</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>D6</td>
<td>Route 1</td>
<td>Non-built-up, B</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>D7</td>
<td>Route 1</td>
<td>Non-built-up, C</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>D8</td>
<td>Route 2</td>
<td>Non-built-up, U</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 2: Type and severity of defects within sections nominated by engineers
4 Introduction to the initial parameters

The development of the Initial Parameters, and the methods for calculating them were reported by Watson et al. (2004) and Nesnas et al. (2004). The parameters provide an estimate of the level of deterioration of the road edge and the transverse profile of the pavement adjacent to the road edge. These estimates are derived from an analysis of successive transverse profiles provided by survey vehicles meeting the SCANNER specification. Table 3 summarises the Initial Parameters, and presents the codes allocated to them for UKPMS. The following sections describe them in more detail.

<table>
<thead>
<tr>
<th>Parameter name</th>
<th>UKPMS Parameter code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coverage</td>
<td>LEDC</td>
<td>Percentage of the reporting length for which sufficient data has been available to allow the identification of the edge of the pavement.</td>
</tr>
<tr>
<td>Edge Roughness</td>
<td>LEDR</td>
<td>Indication of the severity of the short wavelength (0.6m) Longitudinal Profile Variance in the 0.5m strip along the edge of the road.</td>
</tr>
<tr>
<td>Edge Stepping - 1</td>
<td>LES1</td>
<td>Percentage of each reporting length which has a downward step of between 20 and 50mm between the edge of the road and the verge.</td>
</tr>
<tr>
<td>Edge Stepping - 2</td>
<td>LES2</td>
<td>Percentage of each reporting length which has a downward step of greater than 50mm between the edge of the road and the verge.</td>
</tr>
<tr>
<td>Transverse Variance</td>
<td>LTRV</td>
<td>Indication of the difference between the variance in the left and right halves of the transverse profile, after removal of data from off the carriageway.</td>
</tr>
<tr>
<td>Cleaned Rutting</td>
<td>LLRT / LRRT</td>
<td>Rut depths calculated in the standard way, but based on profiles which have had points measured from off the carriageway removed.</td>
</tr>
<tr>
<td>Absolute Deviation of the First Derivative of the transverse profile (ADFD)</td>
<td>LTAD</td>
<td>Indication of general unevenness of the road. This parameter indicates rutting as well as non-rutting defects.</td>
</tr>
</tbody>
</table>

Table 3: Summary of Initial Parameters

4.1 Detection of the road edge and cleaning of the profile

All of the Initial Parameters are derived from SCANNER transverse profile data, which is provided as a set of at least 20 points across the traffic lane, at longitudinal intervals of approximately 100mm.

The first stage in the calculation of all the parameters is the identification of the location of the edge of the road within each transverse profile. This calculation is based on assessment of the shape of the transverse profile, to identify edge like features such as upward or downward steps. Success in this stage is key to the performance of the Initial Parameters.

If the algorithms cannot confidently locate the edge position they will not report an edge location. It is possible to monitor whether the edge has been located within each transverse profile. This then enables us to calculate the coverage, or percentage of the survey length for which a road edge position has been positively located, obtained in any length of survey data. As the edge location is needed for the calculations of both the edge deterioration parameters and the transverse profile parameters, the coverage parameter gives some indication the validity of the values of the Initial Parameters.
Following the identification of the road edge it is possible to “clean” the transverse profiles. The cleaning process is applied to deliver a transverse profile which only contains profile points collected over the surface of the pavement. Hence a cleaned transverse profile has all points to the left (nearside) of the road edge removed (i.e. points defined as being “off the carriageway”). Note that either the original, or cleaned transverse profile is used, as appropriate, for the calculation of the Initial Parameters, as described in the following Sections.

4.2 Initial Parameters for edge deterioration

**LEDR - Edge Roughness.** The ‘Edge Roughness’ measure represents the roughness of the pavement adjacent to the road edge. It is calculated using a short wavelength (0.6m) Longitudinal Profile Variance (LPV) algorithm, which is an established and well-understood method of characterising the unevenness or bumpiness of a pavement. The edge roughness calculations are only concerned with LPV values calculated within the strip covering 0.5m to the right of the edge of the road, the position of which is found using transverse profile information.

**LES1, LES2 - Edge Stepping.** There are two ‘Edge Stepping’ parameters. These indicate the percentage of a reporting length where there is a step down in height from the road surface to the ‘verge’. The two parameters report different sizes of step. Level 1 steps are between 20 and 50mm, level 2 steps are greater than 50mm.

**LTRV - Transverse Variance.** The transverse variance is obtained by calculating the statistical variance for both the nearside and offside halves of the cleaned transverse profile then taking the difference between these two values. A significant difference between the left and right transverse variances may indicate different levels of roughness on one side of the road, potentially indicating the presence of edge deterioration.

4.3 Initial Parameters for transverse profile

**LLRD, LRRD - Cleaned Rut Depths.** The ‘Cleaned Rut Depths’ are calculated by applying the standard TRACS rut depth algorithm to the cleaned transverse profile data. The cleaned transverse profile does not include profile data recorded to the left of the road edge (i.e. off the carriageway). Therefore the cleaned rut depths will not be subject to high false rut depth measurements which can arise as a result of measurements obtained over the road edge.

**LTAD - Absolute Deviation of the First Derivative.** The ‘Absolute Deviation of the First Derivative’ (ADFD) of the transverse profile is a measure of how much the gradient varies between individual points in the transverse profile. This value will be low for a transverse profile that is smooth. Where a profile shows transverse undulations, the value will be higher. Inevitably this means that the value will be higher if there is rutting evident within the profile, but will also be high if there other, non-rutting deformation present. This parameter is a general measure of transverse unevenness, rather than a specific indicator of rutting.

4.4 Implementing the Initial Parameters

The algorithms for calculating the Initial Parameters were originally developed and implemented in TRL’s prototype TRACS/SCANNER processing software. At the commencement of this project work began on a detailed specification for the Initial Parameters. This specification would form the basis of the implementation of the calculation of Initial Parameters in the Highways Agency’s Machine Survey Pre-processor (MSP) and, where necessary, the survey contractor’s own processing software. The process of defining the specifications for the Initial Parameters, and assisting the contractors in their implementation of these specifications was less straightforward than had been originally anticipated. As a result of this it has not been possible, in this research, to include results provided from the current SCANNER surveys, as the routine data was not available. We have therefore used the test dataset described above in our assessment.
However, the implementation of the algorithms by the survey contractors has highlighted a number of areas where the algorithms and methods used in calculating the Initial Parameters could be improved or simplified without degrading the quality, reliability or usefulness of the measurements. We have noted the experience and comments of the survey contractors, and include these where appropriate in the assessment described in Section 5.
5 Assessment of the Initial Parameters

During the development of the Initial Parameters limited work was carried out to investigate the agreement between the intensities of the Initial Parameters and the records provided by CVI surveys over short lengths of the network. The work presented in this section more fully assesses the Initial Parameters and seeks to identify areas for improvement and how the Initial Parameters could be applied in network level condition assessment. The following approach was adopted for this work:

- An assessment was made of the extent to which the Initial Parameters are able to provide data over the classes of road encountered on the local road network (coverage) - Section 5.1.
- The range of values observed for each parameter over the test sites was investigated, to determine initial thresholds associated with sites in poor condition - Section 5.2.
- The agreement between lengths reported to be in poor condition by the Initial Parameters, and those reported to be in poor condition in CVI surveys was assessed. Where appropriate, this included comparison with lengths reported to be in poor condition by manual analyses of HARRIS1 videos – Section 5.3.
- The SCANNER transverse profile parameters ‘ADFD’ and ‘Cleaned Rut Depth’ were compared with standard rut depths, and locations where differences are apparent examined in more detail - Section 5.3.1.

These assessments are described in further detail in the following sections, and the results of the assessment presented.

5.1 Coverage

For the successful identification of edge deterioration using the Initial Parameters it is first necessary to identify the location of the road edge within the measured transverse profile, and then to identify the edge defects at the road edge within the cleaned transverse profile. As stated above, the algorithms to achieve this were derived on the basis of typical TTS (now SCANNER) survey data.

Most survey vehicles currently carrying out SCANNER surveys have a survey width of approximately 3.2m. For local roads it is felt that such systems should provide measurements of transverse profile over the width of the traffic lane for most of the network. However, the road edge falls at the extremity of this survey width. It is probable that on some surveys the vehicle will follow a driving line such that the road edge will not be covered by the survey, or that the edge will be covered to an extent such that the algorithms will be unable to confidently identify the road edge in the transverse profile data. It will therefore become important that survey drivers are aware of the need to ensure edge coverage is as complete as is practically possible.

The coverage for each 10m length was calculated for the sites surveyed, and broken down by road class (‘A’, ‘B’, ‘C’, and ‘Unclassified’), as shown in Figure 1. Here the coverage was defined as the percentage of 10m reporting lengths for which a road edge position was identified within the transverse profiles.
If we specify a quality threshold for coverage, that requires any given 10m length to have 50% or more (vertical red line in Figure 1) of the road edge detected, it can be seen that, of the whole test dataset, 19.5% of the 10m lengths were “covered”. If this approach is broken down by road classification we find:

- All data (not a typical network distribution of A, B, C and U roads): 19.5%
- A roads: 10.3%
- B roads: 21.7%
- C roads: 35.6%
- Unclassified roads: 8.4% (urban sample)

It is therefore apparent that, for the dataset used in this work, the coverage of the road edge could be low, particularly on A roads. These figures could be improved through the use of wider survey widths, and driving lines biased to the nearside of the road. Improvements to the edge detection algorithms also have the potential to provide improved coverage, as discussed later in this report. However, although improvements to the coverage would be likely to improve overall performance, the results of the assessment, discussed below, indicate that such remedial measures may not be necessary for the Initial Parameters.

### 5.2 Range of parameter values

By examining the entire dataset available to us we are able to determine a range of typical values for each parameter, and determine the relationships between Initial Parameter values and the condition recorded in the reference data. Typically it is appropriate to assess the ranges of values in terms of percentiles. Table 4 shows both the 65th and 95th percentile levels calculated from the entire dataset, for each Initial Parameter, reported over 10m lengths.
It is of note that both percentile values for the Edge Step Level 2 (steps greater than 50mm downwards from the road) are zero. This means that over 95% of the 10m lengths had edge stepping less than 50mm. It was found that only 2.4% of the 10m lengths contained Level 2 steps.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Measurement Units</th>
<th>65th Percentile</th>
<th>95th Percentile</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Edge Roughness</strong></td>
<td>Ratio, 0-1</td>
<td>0.036</td>
<td>0.162</td>
</tr>
<tr>
<td><strong>Edge Step L2</strong></td>
<td>Percentage, 0-100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Edge Step L1</strong></td>
<td>Percentage, 0-100</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td><strong>Transverse Variance</strong></td>
<td>Measure, mm²</td>
<td>7.22</td>
<td>71.08</td>
</tr>
<tr>
<td><strong>Edge Coverage</strong></td>
<td>Percentage, 0-100</td>
<td>10</td>
<td>100</td>
</tr>
<tr>
<td><strong>Absolute Deviation of</strong></td>
<td>Measure, Scalar</td>
<td>0.01492</td>
<td>0.02932</td>
</tr>
<tr>
<td><strong>First Derivative</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Cleaned Rut L</strong></td>
<td>Measure, mm</td>
<td>4.80</td>
<td>12.10</td>
</tr>
<tr>
<td><strong>Standard Rut L</strong></td>
<td>Measure, mm</td>
<td>6.91</td>
<td>15.56</td>
</tr>
<tr>
<td><strong>Cleaned Rut R</strong></td>
<td>Measure, mm</td>
<td>4.50</td>
<td>10.20</td>
</tr>
<tr>
<td><strong>Standard Rut R</strong></td>
<td>Measure, mm</td>
<td>4.37</td>
<td>9.86</td>
</tr>
</tbody>
</table>

Table 4: 65th and 95th percentile values for Initial Parameters, as calculated on test data.

Note that the nearside (left) cleaned rut depth values at the two percentile levels are lower than the standard rut depth values (highlighted in blue text). This is due to the cleaning algorithm’s ability to remove kerb or verge features by removing points recorded outside the width of the carriageway. It can be seen that on the offside (right), the cleaned rut percentile values are slightly higher than the standard values (highlighted in red text). The removal of the road edge does not directly affect the offside measurement. This slight increase in rut depth (by 0.34mm at the 95th percentile level) is a result of the cleaning algorithm using a cubic spline interpolation between the measured profile points. This interpolation can raise, by a small amount, the level of rutting determined from the straight edge simulation used to calculate the rut depth.

5.3 Identification of Edge Deterioration

Comparing the reference data, as described in Section 3.2, with the Initial Parameter values, shows us how the different methods for detecting the presence of edge deterioration relate to each other. However, we have to accept that Initial Parameters do exhibit a significant amount of noise. This is shown in Figure 2 which compares the ‘Edge Roughness’ and ‘Transverse Variance’ parameters with the CVI Edge Deterioration values reported over 10km of the Hampshire data. Note that the Edge Roughness values shown have been multiplied by a factor of 1000 to allow them to be plotted on the same scale as the Transverse Variance parameter. The degree of noise evident in Figure 2 reflects localised uncertainties in the values provided by the Initial Parameters.
Figure 2: Plot of 10m results for Edge Roughness and Transverse Variance, alongside 20m CVI edge deterioration results. 10km of Hampshire data

Figure 3: Plot of 1km results for Edge Roughness and Transverse Variance, alongside 1km CVI edge deterioration results. 10km of Hampshire data
Figure 3 re-plots the data of Figure 2, with the data aggregated over 1km reporting lengths (see below for a description of the aggregation process). This approach attenuates the noise, enables better visual comparison between the datasets, and reduces concerns associated with alignment of the datasets. The data shown in Figure 3 is therefore easier to interpret than that in Figure 2. However, it is acknowledged that use of 1km lengths may not be useful in maintenance planning and for the selection of lengths in need of further investigation. For this application shorter lengths may be more appropriate. 100m lengths offer a reasonable compromise between noise reduction and detail. Such an approach is considered in Section 7, where use for maintenance investigation is discussed. In this Section we shall consider 1km lengths.

We must remember that the CVI reports do not include any additional detail attempting to explain why the site has been categorised as having an edge defect. From the CVI report alone it is therefore impossible to determine whether the site suffers from overriding, potholes, general roughness at the edge of the road, or any other defect. The reference data based on the manual analysis of the video footage has attempted to indicate which defects are affecting which lengths of road. This video data is unlikely to be a perfect reference as it is very hard to determine the true extent of defects relating, for example, to the roughness of the edge of the road from video images alone.

### 5.3.1 Comparison with CVI

Figure 4 and Figure 5 compare the values of the Initial Parameters with the results of CVI surveys carried out in Hampshire and Leicestershire. The CVI data is plotted as the average severity obtained over the 1km reporting length. The values plotted for the Initial Parameters represent the number of 10m lengths within each 1km reporting interval for which the 95th percentile level, as stated in Table 4, was exceeded. Figure 4 concentrates on the Edge Roughness and Transverse Variance, whereas Figure 5 shows the Edge Stepping. Note that the CVI data is the same for both figures, as it cannot be broken down further, and therefore it is assumed to encompass all edge defects in the assessment of severity.

![Figure 4: Comparison of CVI data and Initial Parameters (Edge Roughness and Transverse Variance) from routes in Hampshire and Leicestershire.](image-url)
Figure 5 gives an indication that lengths of the road where the CVI data indicates edge deterioration is present are highlighted by the Initial Parameters as containing edge defects.

Unfortunately, although the data appear reasonably well aligned and visually in agreement, it is hard to back this up quantitatively. TRL’s experience with data of this nature suggest that this is often the case and that a visual assessment of the trends evident in datasets is often the easiest and most effective way of determining how well different datasets agree with each other. This is especially true in cases such as these where there is no absolute reference dataset which can be completely trusted, and where there are possible issues with the precise alignment of data. For this reason no rigorous quantitative analysis has been performed on the data.

![Figure 5: Comparison of CVI data and Initial Parameters (Edge Step – Level 1 and Edge Step – Level 2) from routes in Hampshire and Leicestershire.](image)

5.3.2 Comparison with manual video analysis

Reference data was obtained for the Hampshire surveys in the form of a manual analysis of the video images provided by the survey vehicle (section 3.2). The analysis of the video reported the length of road within each 10m subsection affected by cracking, fretting, settlement/subsidence and potholes adjacent to the road edge.

It was hoped that this method would enable direct assessment of the capabilities of the Initial Parameters in identifying the defects, which was not achievable using CVI data, which was concerned only with the overall edge condition of the of the road. However, it is noted that the HARRIS video and CVI reference data and are subject to further differences including that they were carried out at different times, there will be variation between the inspector’s opinions and different limitations apply to the two types assessment due to the differences between carrying out a survey either from a moving vehicle or on a video screen. Such differences inevitably complicate any comparison, such that we could not consider any individual dataset to be a definitive reference data against which the new parameters could be compared.

The plots shown in Figure 6, Figure 7 and Figure 8 compare the results of the video manual analysis and the CVI data with the Edge Roughness, Transverse Variance and Edge Stepping parameters respectively. It should be noted that, because the video data are recorded and summarised in a way that cannot be scaled to be equivalent to the values reported by the parameters, the locations of the peaks are of particular relevance in this comparison, rather than the intensities.
It can be seen in Figure 6 that the locations where the manual analysis of the video images has reported roughness at the edge of the road typically agree with locations of peaks in the CVI data. However, there are some differences between these two reference datasets, which may reflect the fact it was not easy to identify edge roughness from the video. The locations of the major peaks in the data representing the Edge Roughness values also generally correspond to the locations where significant amounts of edge deterioration were recorded in the reference data. However, it is also noted that the manual analysis and the Edge Roughness have both reported defects in some locations where the CVI did not report a defect (e.g. 12km). This could indicate that some of the cases where the Edge Roughness and the CVI data do agree arise from genuine defects that were identifiable in the video, but were not recorded in the CVI survey.

Figure 6: Comparison of Edge Roughness with the manual video analysis and CVI data from the Hampshire route.

Figure 7: Comparison of Transverse Variance with the manual video analysis and CVI data from the Hampshire route.
Figure 7 shows Transverse Variance plotted against both the Edge Roughness and the Edge Step/Overriding reported by the video analysis. Reference data regarding stepping at the road edge has been included in Figure 7 because the presence of this defect could also be reflected by higher levels of Transverse Variance. Once again the visual agreement is reasonable. It can also be seen that the video analysis agrees fairly well with the CVI survey, although the video data shows two large spikes indicating the presence of stepping at 25 and 28km which have not been reported by either the CVI survey or the initial parameters. Also, a length of poor agreement with the CVI data can be seen between 5 and 20km where no edge defects were reported by the CVI reference. This length passes through an urban area, and is predominantly kerbed, but does contain some unkerbed and unsupported sections. It is possible that the CVI survey in this area did not record any edge deterioration as, on kerbed roads, other defects might have been more likely, and recording these other defects may have been the focus of the inspection.

Figure 8 compares Edge Stepping (for the two step size categories) with the edge stepping and overriding reported by the video analysis. Figure 8 also shows the results of the CVI survey. Once again, in general the locations of the high levels of response of the Edge Stepping are in agreement with both the CVI and video datasets. However, there are some lengths of disagreement between both the edge stepping and the CVI/manual analysis, and between the video analysis and the CVI. In particular the initial parameters have failed to identify the stepping reported in the video analysis at 25km and 28km.

Bearing in mind the limitations of the reference data, if the information presented in Figure 6, Figure 7 and Figure 8 is considered as a whole we can gain an understanding of the true nature of some of the edge defects present on the site, and the way in which the Initial Parameters detect and report them.

There are two large spikes in the CVI data between 30 and 40 km. Figure 7 shows the Transverse Variance results are not a great match for these peaks. Figure 7 also shows that the video analysis detected only a small amount of roughness at the edge of the road at these locations. However, the degree of stepping, or overriding observed in the video at these locations was significant, particularly at the second spike. Figure 6 shows that the Edge Roughness also reports edge defects at these locations, and Figure 8 shows a response in the Edge Stepping. Therefore, at these locations the CVI data has reported defects, but given no other information. Our second source of reference data, the video analysis, has separated the defects by type and hence highlighted the presence of edge stepping/overriding. The Initial Parameters which responded most strongly, and which most closely
matched the reference data were the Edge Roughness, and the Edge Stepping. However, if we
examine the datasets in general we can seen that Edge Roughness and Edge Stepping are not always
so closely related (for example over the first 20km of the site).

We have already seen that the Initial Parameters tend to give high responses in locations where there
are genuine edge defects. We now see that the relative levels of response of the different parameters
may help to determine what the likely nature of the defect is, and hence contribute to prioritisation.
The example discussed above indicates that when the Edge Stepping parameter reports a high value,
the reference data indicates edge stepping or edge deterioration is likely to be present. When the Edge
Roughness reports a defect it may be triggered by roughness at the edge of the road, but overriding or
stepping may also be present. If both parameters report a defect in the same place then it appears that
there is a very high chance that edge defects are be present.

Knowledge of how the parameters behave in different situations, and how they relate to the defects
reported in the video reference data is of great value when combining the parameters in a combined
edge condition indicator (Section 7.1) as it helps avoid the ‘double counting’ of similar defects when
deriving an index value.

5.4 Identification of Transverse Unevenness

Whereas the assessment of the Initial Parameters in the identification of edge deterioration can be
achieved through comparison with accepted standard methods, such as CVI surveys and video
analysis, the assessment of the Initial Parameters to identify transverse unevenness is not so
straightforward. No standard method for assessing the transverse unevenness of the pavement exists,
beyond the measurement of rutting. The development of the transverse unevenness parameters
recognised that, on certain roads, rutting might not be the most appropriate method of assessment, and
the shape of the road may have deteriorated without rutting being present. Therefore to assess the
performance of the Initial Parameters for the identification of transverse unevenness we have
considered three areas. Firstly we have reviewed the reporting of cleaned rut depths and transverse
unevenness against current standard TTS methods. In the second area we have compared the values of
the parameters with assessments of transverse unevenness provided by engineers. Finally, we have
undertaken a localised assessment of the transverse profiles recorded on lengths of the network where
the Initial Parameters have reported high values.

5.4.1 Comparison with standard measurements of rutting

Figure 9 compares the transverse unevenness (Absolute Deviation of the First Derivative (ADFD))
and the Cleaned Rut Depths with the standard rut depths obtained using the existing TRACS rut
algorithm on the Hampshire and Leicestershire routes. As in the above analyses discussed in Section
5.3, the reported data has been obtained for each parameter by determining the number of lengths
exceeding the 95th percentile level (the most extreme values), and then aggregating and reporting this
over lengths of one kilometre. This will show us which 1km lengths are most affected by severe
examples of the parameter being studied. For the Cleaned and standard Rut Depths, the value shown
is the greatest of the nearside and offside rut for each kilometre.

The plot shows good agreement between Cleaned Rut Depth values and the standard rut depth,
indicating that the cleaning process is not introducing unexpected behaviour into the reported data on
these sites. Where the Cleaned Rut Depth is lower than the standard rut depth it is likely to be due to
the removal of kerbs and verge features from the profile, as discussed in Section 4.3.

The transverse unevenness (ADFD) values generally show high responses where larger rut depths are
reported and particularly where high rut depths are seen for longer lengths, but not at all of these
locations. Furthermore, some of the ADFD response is significantly greater than the rutting, for
example at 30-35km and 150-155km.
Figure 9: Comparison of transverse shape parameters (Cleaned Rut Depth and ADFD), with the standard rut depths obtained on the Hampshire and Leicestershire routes.

There is general confidence that the standard measure of rutting provided is reasonably accurate, there is good agreement (shown in Figure 9) between the new measures of Cleaned Rutting and the standard rutting, and the location of the peaks of the ADFD measure occur where there are high values of standard rutting. This implies that the initial parameters are providing data in agreement with that previously provided and not introducing a large number of spurious values, which could adversely affect engineering assessment.

5.4.2 Comparison with engineer’s assessment

To assess the additional information provided by the Initial Parameters we have compared the values of the transverse profile parameters with condition data provided by engineers.

Hampshire County Council provided information on six sites located on their road network. These sites ranged in length from a few hundred metres, to over 6km. The sites were selected on the basis of being defective in some way, but not necessarily in terms of transverse profile. Information on the nature of the defects present was also provided. This was based on the authority’s knowledge of the sites, in addition to CVI information. Figure 10 shows the ADFD and Cleaned Rut measurements obtained on the Hampshire test surveys. These are plotted along with the standard rut depth values, and, where available, the engineer’s assessment of the transverse profile on the six sites. The six sites were located at:

A. 4km – 7km;
B. 21km – 27km;
C. 31km – 32km;
D. 39km – 40km;
E. 48km – 51km;
F. 58km – 61km onwards.
The severity indicated by the engineer’s assessment for the worst transverse profile defect for each of the six sites is shown in Figure 10. It must be remembered that these six sites are not necessarily the only locations on the survey route where there are transverse shape problems, merely the ones identified by the engineers. It must also be remembered that some of the sites are of significant length, and the use of a single number by the engineer to characterise the transverse unevenness along the entire site is possibly not appropriate. For example Site B is 6km in length. It is unlikely that the transverse unevenness of the road in Site B is constant throughout its length.

Noting once again that we should only concentrate on lengths where engineers expressed an opinion, we could say that the sites identified by the engineers have been identified reasonably well by the Initial Parameters. For example, it can be seen in Figure 10 that sites C, E and F appear to be successfully identified by responses in the new parameters. It is of note that sites C, E and F are also highlighted using the standard rut algorithms. However, examination of the score for site C shows the potential usefulness of the ADFD measurement. The standard rut depth is no higher on this site than on any of the other poor sites. The ADFD parameter does, however, show a large peak at this location. This perhaps indicates that the ADFD parameter has identified a defect in the shape of the transverse profile at this location which is not a straightforward example of rutting.

Similarly, site E has a higher peak in the ADFD. However, this is not proportionately as large, perhaps showing that the measure is not consistently sensitive. The performance on sites A and B is not so consistent. It is noted that, for site B, the local authority reported that there was 1.5km in poor condition within the total length of 6km, but did not report where in the site the poor length was located. The reporting length and alignment of the survey data to the locations identified by the authority introduce some ambiguity into the expectation of a positive response in the new parameters on this section.

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Figure 10: Comparison of transverse profile parameters (Cleaned Rut Depth and ADFD), with the standard rut depths, obtained on the Hampshire route. Also shown are the engineer’s assessments of the transverse profile of six sites in Hampshire identified as being in poor condition.
5.4.3 **Investigation of individual locations**

An investigation has been carried out at locations where the transverse profile parameters provide data that differs significantly from that provided using the standard methods. The individual 10m values of ADFD are plotted for the whole 200km dataset, alongside the standard rut depths (the average of each 10m nearside and offside rut depth measurement) in Figure 11. The average of the nearside and offside rut depth has been used, rather than the maximum, because it was felt that averaging the rut depth from each side would capture information from the full width of the pavement, reflecting the full width information used in the calculation of the ADFD.

Figure 11 also shows the start and end points of each survey site, and 100 point moving averages to show the trends in the rutting and ADFD datasets. By comparing the datasets we have identified locations where the ADFD demonstrates a clear difference in behaviour to the rut depth, for example where the ADFD shows a proportionally higher response. We have examined several transverse profiles obtained at these locations to identify the source of the difference in response. The locations where this has occurred, and where we have examined the transverse profile data, are highlighted in Figure 11 within the short lengths shown by the yellow lines.

Study of the transverse profiles recorded over these lengths found signs of the presence of transverse unevenness other than rutting. Figure 12 to Figure 15 show selected examples of these transverse profiles, showing the different features present within the profiles that have triggered higher values for the ADFD, but have not always generated high rut depths. The located road edge is also shown on the profiles as a vertical purple line and red dot. In these examples the road edge has typically been identified towards the left most edge of the transverse profile.

The transverse profiles shown in Figure 12 to Figure 15 gave levels of ADFD which were proportionately higher than the rut depths obtained from these transverse profiles. For each figure, the chainage at which it is located in Figure 11 is given. In these examples the failure of the rut algorithm to report the level of unevenness, which is correctly reported by the ADFD, can be attributed to a number of reasons. For example, the moderate rutting of Figure 12 and Figure 13 is probably correctly reported, but the transverse profiles show an underlying unevenness that is not measured by the rutting algorithm. Figure 14 shows a significant nearside rut depth but a low offside rut depth. The large depression in the offside is manifested as a “hole” in the transverse profile, and is not a rut, but...
more likely to be a pothole. This has been missed by the rutting algorithm as a result of limitations in the algorithm, but has given rise to a high level of ADFD. Likewise the transverse profile of Figure 15 shows a substantial spike in the profile, but moderate rutting.

Figure 12: Leicestershire Site 2 (102.566km) - Bumpy across the road, humps.

Figure 13: Leicestershire Site 2 (102.590km) - Smaller transverse bumps, closer together, possibly fretting.

Figure 14: Durham Site 1 (149.174km) - Serious holes.

Figure 15: Durham Site 1 (150.217km) - Serious camber and ridge in road.
5.5 Effect of coverage

As reported in Section 5.1, the coverage is considered in terms of the percentage of the reporting length in which the road edge has been located. Failure to identify the road edge will have an effect on each reported parameter, as detailed below:

- The Edge Roughness is calculated using the region of the transverse profile covering 0.5m to the offside of the location of the road edge. If the edge location is unknown, the roughness is calculated using the leftmost 0.5m width of the transverse profile. Therefore the roughness value may not be calculated from the 0.5m strip covering the road edge.

- The Transverse Variance measure highlights differences between the roughness in the nearside and offside. Lengths where the nearside is significantly more uneven than the offside may indicate the presence of edge deterioration. However, if the road edge is not identified then it cannot be known whether the measure has covered the road edge.

- When the road edge is not identified, the Edge Step height is reported as zero. This may under-report the extent of Edge Stepping in any length.

The Transverse Variance parameter utilises information from the full road width (with the edge removed) to identify edge deterioration, the edge roughness uses data from the region of the road immediately adjacent to the identified road edge, and edge stepping uses data measured outside of the road edge. Therefore failure to identify the road edge will have a different impact on the validity of each measure. All of these Initial Parameters may fail as indicators of edge deterioration where the survey vehicle has not covered the road edge.

An automated filter can be applied prior to reporting the results, to remove lengths where the coverage falls below a certain threshold. We have reviewed the effect of such a filter on the data collected in Hampshire. Figure 16 shows the results of applying a coverage filter such that edge roughness is plotted only for lengths with coverage exceeding 30%. The edge roughness without the coverage filter is also shown, along with the results of the video analysis and the CVI survey.

![Figure 16](image-url)

Figure 16: Illustration of the change in performance in the edge deterioration parameters when a ‘minimum coverage’ threshold is applied

It can be seen in Figure 16 that the shape of the Edge Roughness data with the coverage filter is broadly consistent with that obtained without the application of the filter. However, because of the
reduced intensity in the reported Edge Roughness, false positive reports are likely to have an influence on the dataset when the coverage filter is applied. This is especially true if results are reported over shorter lengths, such as 100m. To restore the dynamic range of the data with the filter applied we can lower the threshold for triggering a report of Edge Roughness to the 65th percentile level, instead of the 95th percentile. The effect of this is shown in Figure 17.

Figure 17: Illustration of the change in performance in the Edge Roughness parameter when the a ‘minimum coverage’ and a lowered trigger threshold is applied

It can be seen that, without the coverage filter, applying the 65th percentile results in many false positive responses. Applying the coverage filter improves the agreement with the reference data but the visual agreement is still lower than that obtained when using the 95th percentile level threshold without the coverage check.

It is felt that the relatively small effect of applying the coverage filter to the Edge Roughness (Figure 16), when thresholded and reported over 1km lengths, indicates that the effect of coverage on the measure, while notable, may not be significant for network level analysis. For localised assessment the effect is likely to be more significant, but we have concentrated on the use of the Initial Parameters at the network level – the purpose for which they were originally designed. Hence, the tests detailed above, using our test dataset, have not shown substantial gains in accuracy by using coverage to filter the Edge Roughness results.

It is likely that the relatively small influence of coverage arises from the fact that, for the majority of the roads investigated, the width was such that, even if the edge had not been identified, the edge strip used for the calculation of Edge Roughness remained in close proximity to the true road edge. Hence the Edge Roughness will remain a good indicator of edge condition even if the proximity to the edge is not confirmed. In fact, there is a probability that omitting data through a coverage filter may result in lengths with high Edge Roughness being ignored. Our assessments have shown that similar conclusions may be drawn for the Transverse Variance measure (which is closely correlated with Edge Roughness).

Edge Stepping can only be calculated from profiles where the road edge has been detected. Therefore it is likely that coverage will have the most significant effect on Edge Stepping. This has a bearing on the combined edge deterioration indicator proposed in Section 7.1. With the suggested weightings for the parameters, any lack of coverage, meaning no reported edge stepping, removes 55% of the potential edge condition score for a section. This may have an impact on the interpretation of the indicator for higher category roads with wide carriageways where coverage is reduced.
6 Implementation and development of the initial parameters

The work reported in Section 5 has been carried out to assess the performance of the Initial Parameters using the definitions established at the commencement of the project. This assessment has enabled us to identify properties of the parameters that could be improved. Furthermore, during this project we have worked with the survey contractors (WDM) and the developer of the Machine Survey Pre-processor to implement the parameters for network level application. This also identified areas where work should be carried out to deliver improvements. In this Section we review these findings and the proposed improvements to the algorithms defining the Initial Parameters.

6.1 Observations resulting from the assessment

The assessments have shown that the Initial Parameters are capable of delivering measures of condition that are often in good agreement with other survey methods. Areas where the parameters could benefit from improvement included the coverage, the potential for undesirable side effects in the smoothing algorithm which may be applied to the transverse profile before locating the road edge, and the use of inappropriate (or unwanted) processes in the calculation of rutting. These are discussed in the following paragraphs.

As noted in Section 5, failure to measure a transverse profile over the road edge will inevitably lead to a failure to obtain the most accurate values for the Parameters because the edge will not be detected and the coverage will be reduced. Although we have found that for network level assessment the loss in coverage may not drastically affect the results, it may be appropriate to introduce practical methods to improve the coverage that would increase the usefulness of the data at scheme level. These could include:

- Providing driver training so that appropriate attention is paid to ensuring that the survey driving line is likely to provide coverage of the edge of the road where possible.
- Introducing a system to allow manual recording of survey information relating to coverage. This could record where the survey vehicle is not surveying the road edge, and could include the following reasons:
  - Survey vehicle overtaking static vehicles or features.
  - Adjacent lane or hard strip.
  - Junctions with side roads, including slip roads and surfaced lay-bys.

It is suggested that events or features such as those listed above could be recorded using a push button system, which could be referenced to the survey chainage.

In addition, after examination of the algorithms it was felt that further improvements to the coverage could be achieved through changes to the algorithms used to identify the road edge within each transverse profile. This is because of certain assumptions made in the algorithms used to identify the road edge (see Section 6.2). These assumptions related to the shape of the road to the left of the edge location and were found to be invalid on particularly narrow roads where the profile measurements extended off the carriageway a significant distance. It was also found that the Fourier cross correlation procedure used to map the edge over individual profiles did not perform as well as might be expected under these conditions. Therefore work was undertaken to improve the algorithm and deliver an alternative method, as described below. This work was closely linked to the resolution of issues associated with the measurement of rutting identified, as discussed in Section 6.2, below.

Concern over the smoothing algorithm was derived not from practical observations, but after in depth consideration of the methodology used for the smoothing. Smoothing is applied prior to the calculation of the position of the road edge. This is intended to reduce noise in transverse profiles that have a large number of transverse profile points. We have found that, when applying the smoothing algorithm with its original definition, the smoothing can introduce unwanted discontinuities into the smoothed transverse profile. Interestingly, this effect has not been observed to date because the
current SCANNER systems have an insufficient number of transverse profile points to require
smoothing. However, this may be required if data from higher resolution (e.g. scanning laser) systems
is delivered from the SCANNER survey.

Following smoothing and cleaning of the transverse profile, the specification for the transverse profile
parameters recommends that the standard TRACS rut algorithm be used to obtain the cleaned rut
depths. We have found that some aspects of this algorithm are not necessarily appropriate or required.
For example, the assessment of the validity of the leftmost two points in the transverse profile using
gradient, and the application of a step height check, are not appropriate for the ‘cleaned’ transverse
profiles. Also the fitting of a curve between the two lowest re-sampled points in the transverse profile
to obtain the greatest rut depth does not offer any benefit.

6.2 Observations resulting from implementation by survey contractors

The survey contractors offer a viewpoint which is strongly related to practicality for network surveys,
encompassing experience from a wide range of survey conditions. The implementation of the initial
parameters by the survey contractors identified a number of issues related to the performance of the
algorithms. These included problems with the detection of the road edge on narrow roads, the ability
to measure over both edges on narrow roads, and practical problems with the calculation, including
maintaining the phase of the data during the calculation of the Parameters and making best use of all
of the survey data collected. These are discussed in the following paragraphs.

For some surveys carried out in the SRMCS, it was found that a number of cleaned nearside rut
depths were significantly higher than expected, and sometimes higher than the standard nearside rut
depths. As discussed in Section 5, we would typically expect the cleaned rut depths to be lower, or at
the most only slightly higher, than the standard rut depths. Review of the transverse profiles from
selected sites showed that transverse profile data had been measured some distance to the left of the
nearsie edge. This behaviour was not observed to any notable extent on the test dataset used in our
assessment, and is due to the very narrow nature of the roads surveyed in the SRMCS. The range of
unusual shapes and features which can be encountered off the carriageway is such that they can cause
problems for the edge location procedure, which currently assumes that the transverse profile will
have a certain typical shape. Investigation of this problem found that some of the assumptions made in
the algorithms identifying the road edge did not hold under the conditions experienced on the
network. The failure of the edge detection algorithm led to problems with subsequent data processing,
and hence generated poor rut depths.

The survey contractors also found that, on certain roads, the width is so narrow that both the nearside
and the offside edges are included in the measured transverse profile. However, the algorithms within
the Initial Parameters assume that only the nearside edge is covered. Work was required to determine
if the algorithms could be modified to enable coverage of both edges, and to develop methods to
enable this to be achieved.

A number of practical observations were made associated with the calculation of the road edge
position and road edge roughness. Calculation of the road edge position currently requires that a fixed
number of transverse profiles be averaged in order to obtain an “average best profile”. This “average
best profile” is then used to obtain the edge position. Because a fixed number of profiles is used for
this stage, whereas later stages of the algorithm specify that calculations be carried out over 10m
boundaries, a phase difference can be introduced when the spacing of the original data is not exactly
0.1m. Similar practical issues were noted in the calculation of edge roughness, where it was pointed
out that some data was being discarded during the calculation, which could actually be included.
Modifications to the specification were required to resolve these problems.
6.3 Developments to the initial parameters

6.3.1 Initial Parameters for Transverse Unevenness

As a result of the above observations work was carried out to improve the algorithms for the measurement of transverse unevenness.

- **Edge Location.** The specification has been modified to improve road edge placement accuracy, to make it more robust on narrow roads and also to improve the percentage of transverse profiles in which the edge is identified (i.e. improve coverage). Changes have been made to the method for locating the road edge within an ‘averaged’ profile. This will improve performance on narrow roads and the different verge profiles that may be encountered. The method used to locate this edge within each individual profile has also been changed. This no longer uses the Fourier cross correlation procedure, but makes use of an alternative cross correlation procedure, which was found to be more accurate.

- **Edge Location.** The specification has been modified to enable edge location in the offside on very narrow (single-track) roads. This is applied as a symmetric application of the modified method, and will improve the calculation of the parameters such as the offside rut depth and transverse unevenness. A further development of this could be the reporting of edge deterioration defects for both sides of the road from one set of survey data. However, this development has not been undertaken in this work. On the A, B and C road network (using current SCANNER survey methods) it is unlikely that such a method would give sufficient coverage. However, it may be more successful on unclassified roads. Further reference datasets would be required to confirm this.

- **Edge location (phase).** The specification has been modified so that, when calculating the road edge location for each transverse profile, a one metre averaging step is applied from the beginning of each reporting interval to prevent the accumulation of phase differences between the one metre averaging and the ten metre reporting intervals.

- **Calculation of Cleaned Rut Depths.** Improvements were undertaken to the algorithm for use in the calculation of ‘Cleaned Rut Depths’. This includes changes to the current procedure that applies a gradient check using just the first two points, and removal of the process of fitting a curve to interpolate between the two lowest cleaned profile points to obtain the greatest depth.

- The performance of the Cleaned Rut Depth parameter has been improved by the improvements in the edge location method described above. More accurate location of the edge reduces the possibility that a kerb or bank will contribute to the rut depth measurement.

- **Smoothing.** The smoothing algorithm (which is only applied to transverse profile data that is measured at a spacing lower than 25mm, so this step is not currently applied to current SCANNER machines) has been modified to give a continuous profile right to the end of the profile.

- **Re-sampling.** The re-sampling and interpolation of the profile data has been re-defined to accommodate profile data that is not evenly spaced.

- **Absolute Deviation of the First Derivative.** The algorithm is modified so that the cleaned profile point exactly on the road edge is not included in the summations, because the first derivative at this point is not calculated.

A revised specification for the calculation of transverse unevenness parameters is given in Appendix C

6.3.2 Initial Parameters for Edge Deterioration

As a result of the above observations work was carried out to improve the algorithms for the measurement of edge deterioration.
• **Coverage.** Improvement of the edge location algorithm, as described above within the transverse unevenness specification will improve the coverage for all the edge deterioration parameters.

• **Edge Roughness.** An improved definition for calculating edge roughness has been developed. This includes changing the calculation so that variances are calculated along the entire survey length, and not confined to each 10m length (and hence uses all of the data collected, whereas the previous definition discarded data at the start and end of each 10m length).

• **Step Heights.** An improved definition for selecting edge step height.

A revised specification for the calculation of the edge deterioration parameters is given in Appendix B.

### 6.4 Implications of developments

It should be noted that the assessments undertaken in Section 5 have been carried out using the Parameters as originally developed, whereas our work is recommending that the above improvements to the Parameters be implemented. It is felt that, whereas the modifications will improve the robustness of the algorithms, these will not significantly affect the particular outputs. For example, the main development work has been in improving the edge coverage. Hence the values output should be consistent with those previously provided, but where the algorithms may previously have been susceptible to failing to cover a particular length, the revised algorithms will provide valid measures.

An assessment of the improved algorithms has been undertaken using data from the Hampshire route, and a sample of SRMCS data for which the reduced edge location accuracy had resulted in falsely high rut depth measurements. The changes to the methods have delivered an increase in coverage for both datasets. Indeed, the proportion of 10m lengths for which the coverage exceeded 50% has increased from the 15.8% obtained with the original algorithms to 96.7% for the Hampshire site. On the SRMCS dataset the coverage has increased from 7.2% to 78.8%. These large increases indicate that the road edge has been detected in a far greater number of transverse profiles following the improvements than was previously the case using the original approach.

A characteristic of the revised approach is that the method is more confidently able to identify where the road edge when the road edge is close to the nearside end of the transverse profile. Hence the new method generates an increased number of edge locations reported close to the nearside edge of the transverse profile. This is often the result of a small profile feature which was previously overlooked. It follows that the cleaned profile obtained using the new method will be similar to the cleaned profile obtained using the original methods, but with the transverse profile considered to have “covered” the road edge, whereas before the edge was considered to have been missed. The result of this is that the coverage obtained is improved, but the other parameters, calculated after the edge location process, will only be slightly different. We have undertaken analyses to confirm this.

A further characteristic of the new methods is the ability to cope with the more challenging transverse profiles presented on very narrow roads. Such roads were not covered to a great extent in our English test sites, but are encountered on the Scottish SRMCS. We have undertaken further analyses to determine if the improvements lead to better performance on the data from such sites.

The nearside cleaned rut depths are plotted below, calculated before and after the improvements, for the SRMCS data (6km) (Figure 18) and the first 6km of the Hampshire site (Figure 19). For the Hampshire site, it can be seen that the results obtained following the improvements are very similar to those obtained prior to the changes being made. The improved edge location on this site has led to slightly better cleaned profiles, which in turn has led to slightly lower rut measurements, but the changes are very small. This was found to be the case for the entire Hampshire survey route. It can be seen that for a significant part of the SRMCS site, large, and unrealistic, rut values were reported by the original method. However, following the improvements this is no longer the case. This indicates that the improved method is better suited to the more challenging roads surveyed in the SRMCS than the original method.
Figure 18: Nearside Cleaned Rut Depth values for the SRMCS data, calculated using the original and improved methods.

Figure 19: Nearside Cleaned Rut Depth values for the first 6km of the Hampshire site, calculated using the original and improved methods.

Figure 20 shows the frequency distribution of different levels of rutting for the SRMCS dataset (left plot) and the Hampshire data (right plot), when considered over 10m lengths. It can be seen that, for the SRMCS data, the improved method has greatly reduced the proportion of data with high rut depths reported. The change seen in the Hampshire data following the improvements is much less dramatic. This is to be expected, as the Hampshire data was not collected on the narrow roads represented in the SRMCS data. This same pattern can be seen in the plots for transverse unevenness (ADFD) in Figure 21. Transverse unevenness is calculated using the cleaned transverse profile after data to the left of the edge has been removed. Before the modifications the transverse unevenness was often calculated using parts of the profile measured over the verge in the SRMCS data, with improved removal of the verge the distribution has changed with the false high values removed. However, as with the rut measurements, the transverse unevenness results for the Hampshire data have changed little.
The Edge Deterioration Indicator incorporates Edge Roughness, Transverse Variance and two levels of Edge Stepping. The frequency distributions of the values of this indicator before and after the modifications are shown in Figure 22.

It can be seen in the plot for the Hampshire site (Figure 22, right) that the distribution of results for the Edge Deterioration Indicator has changed little. Though the coverage has increased significantly, the parts of the profile used for the calculation of Edge Roughness and Transverse Profile has only slightly altered, and the increased coverage was found not to result in a significant change to the levels of Edge Stepping reported.

For the SRMCS site the old data (Figure 22, left) indicates a large number of lengths reporting an Edge Deterioration Indicator between 40 and 50. This spike in the distribution has disappeared with the more accurate edge location obtained with the improved algorithms. This reflects the fact that, prior to the improvements, on the narrow roads of the SRMCS, the Edge Roughness and Transverse Variance were calculated using transverse profile data measured from over the verge. By using this incorrect data the Edge Deterioration Indicator from the affected lengths will often have had large, near maximum contributions from these parameters. No Edge Stepping contribution will have been made to the Edge Deterioration Indicator as no edge will have been detected. Because of the way in which the Edge Deterioration Indicator is calculated, high values for Edge Roughness and Transverse Variance contribute significantly to the overall Indicator value.
Variance combined with no Edge Stepping will often result in an Edge Deterioration Indicator score of between 40 and 45.

Figure 22: Distribution of values, Edge Deterioration Indicator calculated before and after algorithm improvements, for (left) SRMCS data, and (right) Hampshire site.

In summary, we find that the improvements to the algorithms provide greatly increased coverage on all of our datasets. However, on the sites used for our assessment in Section 5 (‘normal width’ A, B and C class roads), the reporting of edge defects have not been dramatically affected. Conversely, it has been found that the improvements have delivered a significant reduction in the false reporting of large rut depths on some sites, particularly on narrow roads. This has been seen in particular on the data from the SRMCS, where the improvements have increased the robustness of the parameters enabling them to be applied with greater confidence on narrow C and U class roads.
7 Using the Initial Parameters for Condition Assessment

Section 5 has reported on work carried out to assess the intensities of the Initial Parameters against reference methods. The assessment has shown that the Initial Parameters often report higher values when there is edge deterioration, or transverse deformation, present. We have also found that the Initial Parameters are capable, to some extent, of reporting specific aspects of edge deterioration. However, the Initial Parameters were designed for network level evaluation, and when applying the parameters for condition assessment consideration of the values of the individual parameters is not necessarily the most appropriate approach. Work has therefore been carried out to develop methods to process and combine the values of the initial parameters for use in condition assessment. This work has considered:

- Combinations of the Parameters, to derive a method for reporting Edge Deterioration as a single parameter - Section 7.1.
- An assessment of the effect of road category on the combined indicator - Section 7.1.4.
- The use of alternative reporting lengths and the effects on accuracy and reliability versus location precision has been explored – Section 7.1.2.

The Initial Parameters have been shown to be quite reliable indicators of the presence of edge and transverse profile defects. However, it was also felt that better use could be made of the Initial Parameter outputs, and methods for maximising the value these parameters offered are investigated in this section.

7.1 A combined condition indicator for edge deterioration

A single indicator for edge deterioration is desirable for a number of reasons. A single value reduces the burden on engineers, who currently have to manage the multiple parameters delivered by the SCANNER survey. A single value also offers a degree of continuity over that offered by current CVI surveys. A single value is also more appropriate for the network level assessment for which the Initial Parameters were designed. Furthermore, a single value offers the potential for simple future enhancement and manipulation without having to provide training to engineers. The single value could either be calculated and provided by the survey contractors, or calculated in UKPMS based on the individual parameters.

The development of the single Edge Deterioration Indicator concentrated on the combination of the four Initial Parameters relating to edge deterioration (Edge Roughness, Transverse Variance, Edge Step Level 1, Edge Step Level 2). The typical ranges of values exhibited by these individual parameters have been established for each parameter using the observed range of values on the 200km of available data (see Section 5.2). As noted in Section 5 the sites included a range of both urban and rural roads, and of A, B, C and Unclassified roads. It is therefore felt that the typical values observed are reasonably representative of the local road network as a whole.

For the assessment of the Edge Deterioration Indicator we have drawn on the CVI reference data and the video manual analysis utilised in the assessment of the Initial Parameters. We have also drawn on a further reference data set provided by local authority engineers in Hampshire, Leicestershire, Shropshire and Durham. This second dataset contained a set of sites for which the local authority engineers provided a general assessment of edge condition.

7.1.1 Calculation of Edge Deterioration Indicator

An Edge Deterioration Indicator is calculated for each 10m subsection using the four Initial Parameter values. These Initial Parameters do not use the same units or scales for measurement; therefore it is necessary to normalise their outputs in order to combine them. The normalisation process assigns a value between zero and one to each parameter based on whether or not, and how far, it is above a specified lower threshold ($T_{lower}$), as illustrated in Figure 23.
Figure 23: Illustration of normalisation process for individual Initial Parameters

Below $T_{lower}$ the parameter is assigned a score of zero. Above $T_{lower}$ the parameter score is increased linearly until the parameter value reaches an upper threshold ($T_{upper}$). At, and above, $T_{upper}$ the score continues to be one, regardless of how far over the upper threshold it is. The values for $T_{upper}$ and $T_{lower}$ are set as the 65th and 95th percentile values for each parameter, which are determined from the 200km dataset available.

This approach to weighting the individual parameters is similar to that adopted for the calculation of the SCANNER Road Condition Index (McRobbie et al., 2006). The normalised parameter values are then combined to obtain an Edge Deterioration Indicator with a value between 0 and 100.

In summary, for each parameter, value $x$, calculate the normalised value $y$:

- If $x \geq T_{upper}$, $y = 1$.
- If $x \leq T_{lower}$, $y = 0$.
- If $T_{lower} < x < T_{upper}$, $y = (x - T_{lower}) / (T_{upper} - T_{lower})$.

The value of the Combined Edge Deterioration Indicator is calculated as follows:

$$\text{Edge Deterioration Indicator} = W_r y_{edge \text{ roughness}} + W_{tv} y_{trans \text{ variance}} + W_{E1} y_{edge \text{ step 1}} + W_{E2} y_{edge \text{ step 2}}.$$  

To determine the weighting values for each parameter ($W_r$, $W_{tv}$, $W_{E1}$, $W_{E2}$) we have considered how closely each parameter was related to the observed edge deterioration in the reference datasets (CVI and manual analysis of video), and the relative accuracy of each parameter determined during this work. A slightly higher weighting is considered appropriate for parameters judged to have a higher level of accuracy. Furthermore, we have considered the effects of combining parameters that report on similar defects and would therefore unevenly weight the indicator if given similar weightings. For example, Edge Roughness and Transverse Variance are both measurements of the roughness of the road surface, but are calculated differently. Edge Roughness uses only the profile data collected adjacent to the road edge, whilst Transverse Variance is calculated using the cleaned profile over the full road width and hence is less fundamentally linked to the road edge. In order to make use of both parameters in the indicator, but to avoid double counting any particular defect, a higher weighting was given to Edge Roughness. Following this, largely qualitative, assessment we recommend the following weightings:

$$W_r = 30$$  
$$W_{tv} = 15$$  
$$W_{E1} = 25$$  
$$W_{E2} = 30$$

The Edge Deterioration Indicator can be calculated over greater reporting lengths by averaging the values reported for each 10m length over the required reporting length. Figure 24 shows the values of the Edge Deterioration Indicator obtained over 1km lengths, compared with the CVI data for the Hampshire and Leicestershire test routes, along with the results of the manual analysis of the video.
images, where available. Note that the Leicestershire data, where video data is not available, begins at approximately 62km.

Figure 24: Comparison of Edge Deterioration Indicator with CVI reference on the Hampshire and Leicestershire test sites (1km reporting length).

Figure 25 re-plots the data shown in Figure 24 from Hampshire, but shows data aggregated over 100m reporting lengths. It can be seen from Figure 24 that, when expressed over 1km lengths, there is general agreement between the Edge Deterioration Indicator and the reference. Locations where the Edge Deterioration Indicator is non-zero agree well with the locations where at least one of the reference sources reports edge deterioration. Similarly, consistently low levels of edge deterioration in the reference are generally associated with low levels in the Edge Deterioration Indicator. When the data is expressed over 100m lengths (Figure 25) the agreement in shape is still reasonable, but with more noise in the data. It was found that reducing the lengths further, to 10m, introduced a significant level of noise and decreased the agreement in the shape. These 10m results are not shown here.
The values of the combined Edge Deterioration Indicator (over 1km lengths) are compared with the condition assessments provided by local authority engineers for sites within the Hampshire, Leicestershire, Shropshire and Durham test routes in Figure 26. The height of the line showing the engineering assessment illustrates how each section has been rated by the local authority engineer. The highest severity level for an edge related defect for that site has been used for the plot to indicate the severity of the most significant defect(s) in each case. Note that lengths at zero are those for which no assessment was provided by the engineer. Hence, the locations of all poor sections in the survey length are not necessarily included in the engineering assessment data, and lengths having a high value for the Edge Deterioration Indicator and no corresponding engineering assessment should not be considered to represent false positives. Furthermore, as different engineers have assessed each site, there may have been different approaches to scoring and site selection.

Noting once again that we should only concentrate on lengths where engineers expressed an opinion, some agreement can be seen in Figure 26 between the sections deemed poor by the engineers, and those lengths with higher values of the Edge Deterioration Indicator. The spikes in the engineer’s assessment generally agree with the higher values of the Edge Deterioration Indicator. There are, however, some discrepancies where a section identified by the engineer as having poor edge condition has a low score for the Edge Deterioration Indicator, most notably between 152 and 166km. A similar false negative result is obtained at 192km and 198km, where poor engineering assessments are not reflected in the reported Edge Deterioration Indicator values.

Further investigation provides some answers as to why the discrepancies are seen. The site between 152 and 166km is located on a wide ‘A’ road linking to a motorway. The edge coverage achieved on this site was 11%, slightly above the test dataset average for ‘A’ roads. Examination of the forward facing video from this location found that most of the site was kerbed, and that, in those places where no kerb was present, the verge was raised at the edge of the road. These factors resulted in negligible amounts of edge stepping along the site. For such roads, the surface of the carriageway adjacent to the edge is most important in determining edge condition and the indicator is dependant upon the Edge Roughness and Transverse Variance parameters. The video for the site often featured a patched surface adjacent to the kerb, cracking and damp patches at the road edge, which can indicate an edge surface condition problem. These defects result in poor general appearance but will not necessarily result in measurable profile defects. This could be one reason why the engineer’s assessment is not always matched by higher values of edge roughness or transverse variance.
Figure 27 shows the 10m Edge Deterioration Indicator values, and the video reference data for the length between 152 and 166km. The separate Edge Roughness and Transverse Variance parameters were examined for the site. The contribution of these parameters to the indicator is related to the parameters lower and upper thresholds as described in section 7.1.1. Only 5.8% of the reported 10m Edge Roughness values within this length exceeded the lower roughness values threshold, the 65th percentile of the whole dataset. Similarly the 95th percentile upper threshold was exceeded by only 0.15% of the data. The equivalent values for the Transverse Variance difference were 8.6% and 0%. This indicates that, compared to the rest of the dataset, the edge of the carriageway is not particularly rough. However, although the average values are low, there were isolated peaks in the data, indicating that the edge of the road was rough in a few isolated locations.

The engineer’s assessment for this site reported that there was a fairly severe level of longitudinal unevenness and poor ride quality, and that the site contained edge potholes and excessive patching of the edge. The type of deterioration which has caused the engineer concern on this site does not appear to have been picked up very successfully by the Initial Parameters. There are a number of possible explanations for this. For example, the users and engineers may have different acceptability levels for different road types and average traffic speeds, whereas the indicator treats all roads the same.

It is possible that the use of different deterioration indicators on different road types could help improve the situation. For example, different thresholds could be used according to road class, speed limit, or road width. Alternatively, the way in which the Edge Deterioration Indicator is calculated could vary on different road types, or with different road widths. For example, on kerbed roads, or roads with supported edges, it may be advisable to calculate the Edge Deterioration Indicator in a way that gave less emphasis to Edge Stepping, which would be unlikely on such a road. However, we have not pursued the development of such alternative indicators in this work.

For the section between 182 and 185km the engineer’s assessment reported excessive patching and poor reinstatements, as well as carriageway cracking and poor ride quality. Analysis of the survey video found this length to be an urban road passing through a small town. As noted by the engineer, multiple patches and reinstatements were observed, however the quality of these features and their effect on ride quality cannot be determined from the video. It is possible that the machine measurements of the effect on ride quality has reported no problems here because the reinstatement repairs are sound, despite appearing excessive.
In the section between 191-197km, the major problem reported by the engineer was badly aligned ironwork. In such cases the Edge Roughness measure would be very likely to show a high value for a very short duration. However, in the absence of any other significant defect (and none were visible on the video) the averaging process would result in a low overall level of edge deterioration.

This investigation suggests that the Edge Deterioration Indicator is better suited for use as a network tool (identifying problems over longer lengths), than it is for identifying and locating individual potholes or spot defects. It also shows that it will not detect every type of defect of interest to the engineer (such as excessive, but sound, patching). Furthermore, whilst an engineer will be able to make an assessment appropriate for a particular road type and site, based on a whole range of environmental and social factors, as well as their own subjective opinion, the Edge Deterioration Indicator, and Initial Parameter values are objective physical measurements. These will behave the same way and report consistently for all sites.

7.1.2 Selection of reporting length

Typically SCANNER data is assessed over 10m lengths to report condition. However, in this work we have considered longer lengths, of 100m or 1km, when assessing the performance of the Initial Parameters, and when considering the combined Edge Deterioration Indicator. It is felt that these longer lengths accord with the original aim for the Initial Parameters - to target lengths containing edge deterioration at the network level, as discussed in Section 4. Furthermore, use of longer lengths in the comparisons has, partially, resolved the issues associated with location referencing arising from multiple data sources, in multiple formats.

The problems associated with multiple data sources will not be an issue in the operational implementation of these methods, hence reducing concerns over data alignment. However, the high degree of noise observed in the Initial Parameters, and the combined Edge Deterioration Indicator when expressed over 10m lengths reduces confidence in the reliability of data, and raises concerns over applying significant weight to any individual 10m report of edge condition.

The trends in the levels of edge deterioration reported using the combined Edge Deterioration Indicator over 1km lengths are seen to match very well with the trends obtained from the reference data. However, such a long reporting length is not particularly suited to identifying locations in need of further attention as the condition of the pavement is unlikely to be exactly constant within a 1km reporting length.

It is therefore recommended that the 100m reporting length for the Edge Deterioration Indicator should give the best balance between incorporating sufficient data to reduce false reports of edge deterioration, and being able to locate poor lengths.

7.1.3 Establishing thresholds for the combined edge deterioration indicator

The Edge Deterioration Indicator produces a score on the scale of 0 to 100. Interpretation of edge condition from this score can be simplified with the use of thresholds to categorise the score into one of a small number of distinct levels of edge deterioration. It is suggested that three ‘severity levels’ would be appropriate, indicating, for example, ‘no significant deterioration’, ‘minor edge deterioration’ and ‘severe edge deterioration’. This categorisation of the edge deterioration indicator score would require two thresholds to be applied (T_lower, T_upper). A three category approach such as this lends itself to the use of a ‘traffic light’ approach (as used in the SCANNER RCI), with lengths below the lower threshold (T_lower) being thought of as ‘green’, those between the thresholds being ‘amber’ and those above the upper threshold (T_upper), the worst on the network, being ‘red’.

To establish initial threshold values for the Edge Deterioration Indicator we examined the CVI data from the survey routes in Leicestershire and Hampshire. Table 5 shows the proportions of the survey routes which were classed as 0, 1, 2 and 3 by the CVI inspections. This shows that, in the eyes of the CVI inspectors, 96.4% of the length on the Hampshire and Leicestershire routes did not include edge deterioration defects.
Table 5: Proportions of survey routes classed as levels 0, 1, 2 or 3 in CVI inspections.

<table>
<thead>
<tr>
<th>Proportion of data (%)</th>
<th>Level 0</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>96.4</td>
<td>0.7</td>
<td>0.7</td>
<td>2.2</td>
</tr>
</tbody>
</table>

It would be appropriate to choose a value for $T_{upper}$ such that the proportion of the road network identified as red by the Edge Deterioration Indicator remains broadly consistent with that reported by the CVI survey. Consequently we used thresholds for the 100m Edge Deterioration Indicator having levels close to this percentage. Table 5 shows the levels of the 100m Edge Condition Indicator relating to the 95th, 96th and 97th percentile values on the Hampshire and Leicestershire routes. A value for $T_{upper}$ of 30, which gives between 3 and 4% of the network as being ‘red’ in terms of edge condition, seems appropriate.

Table 6: Potential values of $T_{upper}$, and corresponding proportions of dataset classed as ‘green and amber’

<table>
<thead>
<tr>
<th>EDI value</th>
<th>Proportion</th>
</tr>
</thead>
<tbody>
<tr>
<td>32.1</td>
<td>97</td>
</tr>
<tr>
<td>28.9</td>
<td>96</td>
</tr>
<tr>
<td>27.8</td>
<td>95</td>
</tr>
</tbody>
</table>

Because the CVI data only appears to report the significant cases of edge deterioration there was no objective, quantified reference data source to help with the establishment of an appropriate level for $T_{lower}$. Experience dealing with indicators derived from TRACS, TTS and SCANNER research suggested that levels between 65% and 75% would be appropriate to indicate less severe deterioration. Table 7 shows the values of the 100m Edge Deterioration Indicator at the 60th, 65th, 70th and 75th percentile levels.

Table 7: Potential values of $T_{lower}$, and corresponding proportions of dataset that would be classed as ‘green’

<table>
<thead>
<tr>
<th>EDI value</th>
<th>Percentile</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.6</td>
<td>75</td>
</tr>
<tr>
<td>8.9</td>
<td>70</td>
</tr>
<tr>
<td>7.5</td>
<td>65</td>
</tr>
<tr>
<td>6.3</td>
<td>60</td>
</tr>
</tbody>
</table>

An initial threshold value for $T_{lower}$ of 10 was deemed appropriate. This gives between 70 and 75% of the network as being ‘green’ in terms of edge condition. Figure 28 shows a histogram of output values from the Edge Deterioration Indicator, and can be used to assess the effects of varying $T_{upper}$ and $T_{lower}$. We can see that a small change in the value of $T_{upper}$ will have a relatively small effect on the proportion of data classed as ‘red’, but the choice of $T_{lower}$ is more critical.
Figure 28: Frequency distribution of Edge Deterioration Indicator values.

Figure 29 shows data from the Hampshire and Leicestershire surveys following the application of the suggested initial threshold levels. The plot compares the output of the Edge Deterioration Indicator, following the application of the suggested threshold values for $T_{lower}$ and $T_{upper}$, with the locations where the CVI reported edge deterioration. The edge defects identified by video analysis is also shown for the Hampshire site only (up to 60km). We can see that there is often agreement between the lengths where the Edge Deterioration Indicator reports level 2, or ‘red’, and the lengths for which the CVI inspection has recorded edge deterioration. The occurrence of red lengths in the edge indicator is lower than the number of lengths report to contain edge deterioration in the CVI survey. However, the method has a reasonable visual agreement and low false positive rate (low number of lengths reported as red in the indicator for which no edge deterioration was reported in the CVI survey). Where available, the video reference data tends to indicate that there were genuine defects at the edge of the road in most of the places where the Edge Deterioration Indicator was triggered at level 1 or 2.

Figure 29: Comparison of CVI, video and Edge Deterioration Indicator outputs for Hampshire and Leicestershire data.

So far in the determination of threshold levels, the 100m reporting of the Edge Deterioration Indicator has been examined. This is because we suggest this reporting length should be used for the indicator, as discussed in Section 7.1.2. Different threshold levels will be required to determine the severity level for the indicator if the indicator is reported over different lengths, such as 10m or 1km. Additionally, it must be remembered that this analysis was carried out on a very small dataset which may not be representative of the entire network.

7.1.3.1 Recommended threshold levels for use with Edge Deterioration Indicator

The following initial threshold values are recommended for use with the Edge Deterioration Indicator when using data averaged over 100m lengths:

\[
T_{lower} = 10 \\
T_{upper} = 30
\]
7.1.4 Effect of road category

The comparison of the Edge Deterioration Indicator with CVI and engineering opinion appears to show a reasonable degree of agreement on the test dataset. However, we can obtain a further degree of confidence in the Indicator by examining the trends demonstrated on different road categories.

Figure 30 shows the percentage of lengths reported to have a non-zero severity of edge deterioration in the CVI surveys carried out over the Hampshire and Leicestershire test data set for road types ‘A’, ‘B’, ‘C’ and ‘Unclassified’. This is compared with the proportion of 100m lengths for which the combined Edge Deterioration Indicator value was greater than the suggested lower threshold for each road type. Note that different scales are used for the combined Edge Deterioration Indicator and CVI results, the absolute intensities being less relevant for this comparison than the trends. It is apparent that the two sets of data vary between road class in much the same way, with the level of edge deterioration increasing as the road class decreases. The results appear to show that the variation in results for the Edge Deterioration Indicator across road classifications is as would be expected, and in agreement with the variations shown by the CVI reference.

![Figure 30: Comparison of trends in the degree of edge deterioration reported by the CVI survey and combined edge condition indicator, by road type.](image-url)
8 Enhanced techniques using new technologies

The second stage of this work has pursued the development of further techniques for detecting and quantifying edge deterioration. However, whereas the work on the Initial Parameters has concentrated on technology typical of that used for current SCANNER surveys, this research has considered the use of technology that is currently available, but not necessarily used in current commercial measurement systems.

8.1 Data Collection

Data has been collected using the Highways Agency’s HARRIS2 research survey vehicle to assist with the development of these new methods. HARRIS2 uses state of the art road measurement technology which is currently not in routine use on the network. For this research the system consists primarily of a downward facing colour image collection system covering a survey width of nearly four metres, combined with a transverse profile measurement system utilising a scanning profile laser, also covering a four metre width, capable of providing highly accurate transverse profile data spaced at small transverse spacings. Figure 31 shows both schematic and photographic views of HARRIS2.

Figure 31: The HARRIS2 survey vehicle

The SCANNER initial edge deterioration parameters assessed in Section 3.1 are based on the capabilities of the current SCANNER survey vehicles, which are typically able to obtain transverse profile and greyscale image data up to and just over the edge of the road surface (although the DCL/Roadware ARAN SCANNER system does measure over a survey width up to 4m). The enhanced profile and colour image data collected by the system on HARRIS2 extends 1m outside of the vehicle width, and as such is much more likely to measure over and past regions of overriding on narrow roads. As well as the increased profile survey width, the profile is measured and reported at a higher longitudinal and transverse resolution than is typically the case in SCANNER surveys. This
enhanced profile data combined with the colour image data means that features such as kerbs, overriding and potholes can be measured. Therefore, this work has aimed to use the more detailed data to enhance the measures provided by the current initial parameters (in terms of accuracy and coverage), and also to identify further characteristics, currently not reported by the initial parameters. These include:

- Is the edge supported or kerbed?
- Identifying potholes in the surface near the edge
- Segmenting the image to enable the crack detection algorithms to identify cracking of the surface near the edge.
- Identifying overriding
- Improving the demarcation of road edge
- Assessing overall appearance, particularly relating to patching

8.2 General Approach

The development of enhanced methods for automatic assessment of road edge condition has been separated into a number of steps:

- Utilisation of image processing algorithms and profile analysis algorithms to ‘extract’ or locate features or boundaries of interest, such as the road surface edge or paved verges.
- Interpretation of the features identified in the first step to identify particular defects, such as potholes.
- Developing appropriate means for reporting the intensity of defects as a single value for each reporting interval (e.g. 10m).
- Developing a single value indicator of the level of ‘Edge Deterioration’, combining the results for individual edge deterioration defects in an appropriate and informative way.

8.3 Algorithms

The image and profile processing methods applied in this work have built upon previous work carried out in this area under TRF’s reinvestment research program. The basic set of algorithms provided by the reinvestment research were applied in this work to the data collected on the test data sets to provide an initial assessment of their capability. This was followed by targeted development aimed at resolving issues identified in the assessment, and then identifying the required features. The following summarises the algorithms, a more detailed outline is provided in Appendix D.

8.3.1 Image Processing

The automatic image analysis methods primarily aim to locate the edge of the road surface. Detecting the edge of the road surface from the image as well as from transverse profile data (the approach used for the initial SCANNER parameters) gives greater confidence in the accuracy of the road edge location. It also allows the road edge to be identified in situations where the profile does not contain a step edge across the road-verge boundary.

The algorithms make use of the information available from the HARRIS2 colour images taken over the road edge. Hue, saturation and intensity images are calculated from the red, green and blue pixel values. The paved road surface in the image is characterised by calculating certain statistics from the hue and saturation values from a defined region to the right of the image. Using hue and saturation, but not intensity, reduces the sensitivity of the method to shadows and sunlight. Iterative methods are then used to locate the leftmost extent of the road surface.

Whilst locating the leftmost extent of the road surface, the boundary between an overridden verge and intact vegetation can be located. The gap between this ‘verge edge’ and the ‘road edge’ can indicate the width extent of an overriding defect.
Additional information is obtained from the image to identify whether the paved surface extends to the left edge of the image, indicating that the image does not extend past the road edge due to driving line, a side entrance or adjacent lane, or that there is a paved verge surface such as a footway.

HARRIS2 collects two “columns” of images using cameras positioned on the nearside and offside of the vehicle. When viewed side by side the images cover a transverse width of almost 4m, with a slight overlap. For the purposes of locating the nearside road edge in our test dataset, only the nearside images need to be analysed.

**8.3.2 Transverse profile analysis**

The road edge location algorithms aim to locate any road step edges that can be identified from the transverse profile data. A step edge detector is applied to each transverse profile. This detector is applied iteratively along each profile towards the left (nearside) end. The first step of a certain height upwards or downwards is marked as the profile edge. This may occur as a downward step at the edge of a road surface or at the offside edge of a pothole within the road surface, or as an upward step upon reaching a raised kerb, earth bank or vegetation. The step edge positions from all of the profiles define a profile detected road edge.

In order to detect an upwards kerb step edge in situations where a pothole may have been encountered first (as the iterations are carried out right to left), a separate step edge detector is applied which is only triggered by an upward step of a step size appropriate to identify raised kerbs.

**8.3.3 Fusion of image and profile data**

The relative positions of the road edge features located within the transverse profile and image data can be combined due to the fixed relative positions of the measurement equipment on the HARRIS2 vehicle. As a result, further methods can be applied to identify the presence of defects relating to edge deterioration. The methods to identify a number of defects and features are discussed and tested in the following sections. Additionally, the road edge detected from the image and the step edge found in the profile are used to define a ‘combined road edge’. This is defined as the position of the image detected road edge or the position of the profile step edge, dependant upon which is furthest into the road. This combined edge defines a boundary that can be used to segment the image or profile data for the application of methods to identify other surface defects (e.g. those beyond the scope of this project).

**8.4 Approach to Assessment and Development**

Although the assessment of the Initial Parameters (Section 5) utilised standard reference data (CVI), a more detailed test data set was required for the development and assessment of the enhanced methods, that accurately reported the location and extent of the defects. This reflected the aim to achieve a more detailed measure of the edge condition using the enhanced techniques, and would enable the requirements for development to be better targeted.

Therefore a system was developed to enable the transverse profile data obtained using the scanning laser to be superimposed on the colour images, which were tiled to form a continuous scrolling image of the road surface. Where appropriate this display can also be used to show the position of the road and verge edges found using the image data and transverse profile data. A screenshot from the software used to display this data is shown in Figure 32, which shows the images collected using the nearside HARRIS2 camera and the transverse profiles collected with the scanning laser measurement system (red lines – every fifth transverse profile that was recorded is shown).

Outputs of the image and profile processing algorithms are superimposed graphically on the displayed road edge images as shown in Figure 32. A dark blue line traces the points where a step edge has been found in the transverse profile data using the automated system, with the associated step heights listed alongside towards the left of the image (these are sampled from the transverse profile data to show a height every 100mm). Where the step height is negative, no downward road edge step has been found.
and the upward slope of the bank has been detected. The edge of the road detected in the image, and the edge of the verge (or overriding) detected in the image are also marked. These are shown by the green and white lines respectively. A yellow line is shown which represents the ‘combined’ edge, and represents the finally located road edge output from the system.

![Figure 32: Screenshot from the survey image and profile display software, also showing detected edge lines, profile heights (box contains magnified profile height text) and crosses which can be marked by a manual assessor.](image)

To assess the status of the algorithms the location of each of the three edge lines (image road edge, image verge edge, profile road edge) was assessed by the operator against the image and profile data and a subjective judgement was made as to whether the edges had been correctly located. If there appeared to be an error in the placement of the edge, this was recorded. The software allows an assessment to be made every 0.2m, with errors in any of the three automatically produced edges recorded separately. The cross markings to the right of Figure 32 indicate how a square can be marked by a mouse click, and a manual assessment can be carried out in this way by marking lengths where the automatic detection of edge steps or image edges appear incorrect.

The assessment provided by the manual analysis enables both the performance of the data processing algorithms to be established, and forms part of an iterative development programme that directly reports locations where the algorithms are failing, hence enabling targeted development. This iterative process was applied throughout the development of the algorithms to deliver improved performance over that provided by the “original” TRF algorithms at the start of this project.

For the assessment and development we have utilised a 735m rural section from the Hampshire South route and a 1542m built-up kerbed section from the Hampshire North route. The rural section was selected to be comprised of a narrower (C class) road with consistent measurement over the mostly vegetated verge for the majority of its length. It appeared, from viewing the images, to contain a significant amount of overriding. The built-up section contained no vegetated verges, and the edge of the road frequently included kerbs, footways and side entrances. The edge also includes a cycle-lane, which forced the survey vehicle away from the kerbed road edge.

The performances of the data processing methods for identifying edge boundary and profile step features for these lengths are outlined in the following sections.
8.5 Detection of features using enhanced data

8.5.1 Detection of road and verge edge using image data

The iterative development of the image processing algorithms concentrated on improvements to the use of colour information, improvements to the procedures used to segment the image and improvements to the procedures to identify segments belonging to the road, verge and overridden surfaces. At the completion of the development the test sections described above were used to evaluate the performance of the edge detection.

Figure 33 shows an example of successful detection of the road and verge edge by the image processing algorithms. As stated above, we plot the road edge obtained from the image processing in green and the road edge obtained from the fusion of the transverse profile and image data as yellow (the “combined” road edge). In this case the combined road edge algorithm takes all of its information from the image data and hence the figure shows the image derived road edge as yellow. It can also be seen that the image derived verge edge (white) is very close or coincident with the road edge as there is no overridden strip.

![Figure 33: Edge Location on simple road/vegetation boundary.](image)

Figure 34 shows an example which contains a strip of the verge adjacent to the road that does not contain vegetation, and could therefore be a region of overriding. The road and verge edges are again accurately placed by the automatic methods. The gap between the two edges indicates possible overriding. It has been found that for images with a single type of road surface, a well defined edge strip, and a clear area of live vegetation, the algorithms work particularly well.

The algorithm for edge placement has been enhanced for situations where there is a less well defined vegetated region within the image, either because the vegetation is dried out or cut back, or because the driving line has resulted in less of the verge being contained within the image. In this situation the verge and road edge placement are generally well placed by the algorithm. An example is shown in Figure 35, where the lower half of the image shows a non vegetated verge region containing debris. The yellow ‘combined edge’ indicates that the road surface edge has been well located.

Figure 36 illustrates how the road edge placement can be less accurate for a fully paved image containing a kerbstone boundary between the carriageway and the footway. The figure shows (with the green line) that the road edge has been identified on the wrong side of the kerb. We find that the image derived road edge is less successful where there is a footway or other paved surface beyond the road edge. Other methods can be brought in where this situation is encountered, as described in section 8.5.3.
Figure 34: Good tracing of image derived road and verge edges to delineate a region of overriding.

Figure 35: Demarcation of non-vegetated region of verge containing debris.

Figure 36: A “surfaced verge”. The image processing has reported the road edge on the wrong side of the kerb (yellow combined edge is sourced from the profile edge step).
The image processing was less successful where a distinct change in appearance of the road surface occurs adjacent to the true road edge. This can be due to haunch or patch repairs or where the road edge is damp. Improvements to the algorithm have reduced such errors, but it has not been possible to eliminate them. Figure 37 contains a heavily rutted and cracked region at the edge of the road surface, the automatic methods have incorrectly identified the right boundary of this region as the road edge. Further errors could be found at the location of high friction surfacing (HFS). This feature can result in a difference in colour across the pavement that falls outside of the range that the algorithms can tolerate. Therefore the edge of the HFS may be identified as the edge of the road surface.

Figure 37: Example of incorrect image road edge placement (green line).

In summary, the image processing road edge location algorithms have been improved through enhancements to:

- The calculation of colour statistics to allow the algorithms to work with greater consistency across different images and surfaces.
- Improvements to the segmentation to better place the edge line to the left of segments identified as containing the road surface.

Table 8 presents the percentages of the survey lengths where the edge placement reported by the image processing was correct. The image processing algorithms correctly located the road edge on the rural site over 93% of the length. The errors in edge location are mainly attributed to the reasons discussed above. However these errors will not occur for all such features and the performance is dependent upon particular aspects of the data in each case. It is felt from two sites analysed that the extent of these errors is low but should be considered when assessing a larger dataset.

<table>
<thead>
<tr>
<th>Site</th>
<th>Image Road Edge</th>
<th>Image Verge Edge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hants North</td>
<td>89%</td>
<td>91%</td>
</tr>
<tr>
<td>Hants South</td>
<td>93%</td>
<td>93%</td>
</tr>
</tbody>
</table>

Table 8: Percentage of survey length where the image derived edge locations are correct.

8.5.2 Detection of edge stepping using enhanced profile data

Table 9 shows the percentages of the survey length for which the automatic profile analysis was able to correctly identify stepping at the road edge. The automatic step detector (described in 8.3) locates transverse profile steps above a certain size, by calculating the local profile height changes within the profile. A manual assessment of the results of this detector for the test lengths was carried out. This assessment identified where the step was appropriately detected using a method (described in 8.4) which marked locations where the step appeared to be incorrectly placed, for example features of less significance within the road, or by missing a significant road edge step. It can be seen that a high level of accuracy was obtained in the detection of edge stepping on the rural site. The detection of stepping at the road edge is used in combination with the location of road edge in the image to identify edge
defects. Correlation between the location of a downward step and the image derived road edge may indicate the presence of overriding. An upward step could indicate a kerb, a wall or a natural bank feature. However, downward steps located significantly to the right of the image derived road edge, can indicate the presence of a pothole, material loss or deformation within the road surface.

<table>
<thead>
<tr>
<th>Site</th>
<th>Profile Step Edge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hants North</td>
<td>94%</td>
</tr>
<tr>
<td>Hants South</td>
<td>99%</td>
</tr>
</tbody>
</table>

Table 9: Percentage of survey length where the profile derived edge location was correct.

Our assessment of the profile algorithms aimed to determine where the profile step edge was badly placed in relation to the true road edge, or appeared to miss a step feature which should have been identified. Note that failure to identify a step edge between a flush kerb and the road surface was not considered to be an error, because these do not present a significant step at the road edge, and other defects, such as overriding, could still be present where a flush kerb exists.

Although the above performance figures show that the step edge detection is typically highly successful, the identification of the road edge using the profile data does suffer some problems. For example, Figure 38 shows how a downward step at the road edge can be missed (blue line). This can often occur if the step is small or has a smoother transition between the two height levels than may be assumed from the image (and also applies for flush kerbs). This is an interesting observation, showing that the 2-dimensional images can lead to false reporting of deterioration when assessed without the overlaid profile data. In Figure 38 the shape and height of the step visible in the transverse profile data is on the borderline of being detected using our step edge detector. The sensitivity of the detector can be adjusted. However it is not desirable to tune such thresholds to different sites.

![Figure 38: Part location of downward step between unsupported road edge and rutted verge.](image)

8.5.3 Detection of ‘surfaced verges’

Images are defined to contain surfaced verges if the left side of the image is paved (for example where there is a driveway, side turning or footway). The automatic identification of surfaced verges examines the colour properties of either side of the image. This information is used in conjunction with the edge location methods to determine whether the edge is surfaced or if the survey has not covered the road edge (it is not straightforward to distinguish between these two possibilities). The algorithm has worked well for the rural Hampshire South site, detecting driveway entrances or side roads which occurred intermittently along the length of the site. Figure 39 shows the locations within the length where a ‘surfaced verge’ (or entirely paved image) was correctly detected.
With 12m in total incorrect (Table 10), the surfaced verge identification was accurate for 98% of the rural site. False negative reports of a surfaced verge arose from a patched region of overriding and a block paved drive entrance (due to a large difference in the colour of the road and verge material, discussed further below). False positive identification of a surfaced verge arose from non-vegetated earth (or dirt) at the left edge, and a large ‘SLOW’ sign painted upon the road, which reduced the ability of the algorithm to use the road surface colour values.

For the urban Hampshire North site, manual inspection has shown that the survey was entirely surfaced to the left edge with a mix of footways, side entrances and/or additional lanes to the left of the survey vehicle. The automatic method was found to indicate the presence of a fully surfaced image for 91% of the length, distributed as shown in Figure 40.

Examination of the 9% (138m) of images not identified as fully surfaced found that a double-yellow line sometimes fooled the system into determining that the left edge of the image did not contain a surface that was comparable to the road. However this problem only affected a small proportion of the images containing double yellow or white edge lines. For the majority of the false-negative length (116m) the presence of High Friction Surfacing (HFS), that did not extend to the edge of the road, caused the error. Again, the change in colour at the edge of the HFS confuses the algorithms when applied to some images. We have already observed (above) that HFS has an adverse affect on the performance of the road edge detection. It is likely that that the resolution of issues associated with this surface will require separate and dedicated methods to identify such lengths.
Table 10: Performance of the fully surfaced image identification.

<table>
<thead>
<tr>
<th>Site</th>
<th>Length fully surfaced / total length</th>
<th>Length of full surfaced images identified</th>
<th>Length of full surfaced images missed</th>
<th>Length of falsely identified fully surfaced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hants South</td>
<td>34m/735m</td>
<td>30m</td>
<td>4m</td>
<td>8m</td>
</tr>
<tr>
<td>Hants North</td>
<td>1540m/1540m</td>
<td>1402m</td>
<td>138m</td>
<td>0m</td>
</tr>
</tbody>
</table>

Failure to identify a surfaced verge may result in the false positive reporting of defects, in particular the road and verge edges found may lead to the false reporting of overriding. However, it is highly unlikely that this would be accompanied by a downward step in the profile data (if the image is fully paved). Therefore appropriate interpretation of the data (i.e. combining overriding with stepping) would lead to a report of mild overriding, which is not a significant defect, as discussed below.

### 8.5.4 Detection of raised kerbs (without surfaced verge)

Potential methods for identifying raised kerbs from the image and profile data were investigated using both test sites. The sites contained examples of short lengths of raised kerbs at driveway entrances as well as longer lengths of kerbing, both clearly visible and obscured by vegetation and debris.

A significant length of the raised kerbing on the rural site was obscured by vegetation and debris, which prevented the kerbstones from being identified within the image. Although the upward kerb step is generally well detected using the profile data, it is desirable to obtain a positive identification of the kerb within both the profile and the image, so that differentiation can be made between kerbing and a banked earth verge. Indeed, it was found that most of the raised kerbs reported from the profile data actually arose from the presence of a banked verge, and that the kerb stones were not successfully identified from the image. Initially, this resulted in poor performance in the identification of the short kerbed lengths present on the rural site. Problems were also identified on the urban test section. The automated analysis reported only 5% of the length to be kerbed, against the 26% reported in the manual assessment. This low level performance could be attributed to the conservative nature of the algorithms - although the profile algorithms frequently reported upward steps, the algorithms require a positive identification of kerbing in both the image and profile data.

Several methods were pursued to improve the performance - including assessment of the position and size of the stepping, and the effect of the presence of a kerb on the image - to create a kerb indicator, based on the following criteria:

- The kerb edge position is to the right of or equal to the image road edge position and is greater than 0 (the left edge of the image).
- The kerb step height is greater than 100mm.
- The image intensity step is greater than +25 (left side of step is brighter than right side - a kerbstone surface usually appears brighter than the road surface in the image).

Examples of applying this method to identify raised kerbs on sample lengths of the rural and urban sites are shown in Figure 41 and Figure 42 respectively. On the rural site there is still a tendency to under-report the identification of raised kerbs, but there is a low level of false positives. However, this is a challenging site, where many of the raised kerbs are partly obscured. In the urban environment, with less debris vegetation obscuring the kerbstones, the method broadly identifies the kerbed length (note that the profile data was not available for the entire site due to the minimum speed cut-off feature of the scanning laser). It is therefore apparent that the methods are relatively successful, but have some limitations. However, it was found that using less strict rules in the algorithms lead to significant over-reporting of the extent of kerbing. At the current level of performance it is felt that the approach can be used to obtain a broad indication of the presence of kerbing, allowing lengths or sections that are generally kerbed to be identified (see section 8.6.4).
8.6 Reporting Defects and Features

The above sections have described how features (e.g., the location of the road edge) can be extracted by the image and profile data. Further rules can now be applied to obtain information on the presence, intensity and length of particular defects (e.g., stepping) or features (e.g., kerbs), reported in a manner that can be used by engineers. The rules described in this section are developed from those reported in earlier research (Watson and Wright, 2006). The current research has taken these further, with the aim of improving the reliability and accuracy of the reporting of defects and features.

In developing an approach to reporting the presence of defects and features we have aimed to deliver measures that reflect the proportion of the reporting length over which the defect is present. Previous experience, particularly with the initial SCANNER methods, has shown that reporting extent is more informative than reporting an average where the indication of a small length of a significant defect may be ‘averaged out’.

To assess the success of the enhanced methods in reporting the defects and features we have applied the enhanced methods to the HARRIS2 data obtained on the Hampshire sites, as discussed in section 5. This site was chosen because it had the most extensive set of reference data, including a manual reference carried out using the HARRIS survey forward facing video. “Reference” data was also available for this site from the Initial Methods.

8.6.1 Overriding and stepping

We base the reporting of overriding and stepping on an evaluation of the location of the road edges, combined with size of any step edge identified in the profile data. The approach calculates the transverse distance between the road and verge edges derived from the image data. This is the width of overriding. We make a further assessment of ‘rutting of the verge’ if the width of overriding is
significant, and a significant downward step edge exists. For practical purposes, overriding without stepping is considered to have a lower severity than overriding with stepping. The proportion by length where each severity of overriding is present is report.

The output of the automatic detection of overriding for the rural test section is plotted in Figure 43. The two severity levels for the reference shown in Figure 43 were obtained from a manual analysis of the image and profile data. Locations where overriding was evident in the image data with no stepping were assigned a value of one. Locations where the overriding could be associated with stepping were assigned a value of two. It can be seen that the automatic detection of overriding agrees with the reference (Severity 1) in a number of locations, but is subject to a number of false positives. The automatic report of the more severe defect, overriding with rutted a verge, has a tendency to under-report.

The false positive, at 100-130m, demonstrates the difficulty in automatically identifying some particular cases using image data. An example image is shown in Figure 37. It is apparent that a repair has been carried out to the rutted verge. However, a depression remains in the profile and wide cracks have formed. There is little information in the image or profile data to distinguish this region from a strip of overriding. It is beyond the sensitivity of the algorithms to make the distinction that can be made in the manual analysis. However, it could be argued that such a length does contain a defect, but that this cannot be “allocated” to overriding.

The results for the Hampshire dataset are shown in Figure 44. Each of the three series plotted contains values between 0 and 100 percent of the reporting length however the reference and automatic detection of rutting of the verge are offset upwards for ease of viewing. It can be seen that there are some areas where higher density within the automatic results corresponds to a higher density within the reference. However, the automatic identification of overriding (orange plot), identified from the image only, has over-reported compared to the reference in a number of other locations. This output is calculated from the image data only. Consequently it is sensitive to errors in the interpretation of the image and placement of the road and verge edge.

**Figure 43: Rural Hampshire test section, automatic and manual identification of overriding.**

**Figure 44: Hampshire dataset automatic and video reference overriding**
The automatic detection of rutting of the verge (red plot) combines the identification of an overridden width from the image with the identification of a downward road edge step in the same location. As such it indicates a more severe defect, and the positive identification of the defect from two data sources reduces the likelihood of false positives. Therefore this defect is indicated in the Hampshire data (Figure 44) for a smaller proportion of the ten metre lengths, and smaller values are reported for each ten metre length where the defect is found.

It is noted that in generating the reference data, overriding with rutting of the verge is easier to identify from forward facing video data than overriding without rutting of the verge which is a less severe defect with a lower visual impact. Instances of this less severe defect identified automatically from the downward HARRIS 2 images may not be spotted when generating the reference data due to the viewing frame, angle and lower resolution of the forward video. Therefore the reference data is likely to be closer the automatic identification of rutting of the verge, and the automatic indicator of overriding is likely to contain correct results missed by the reference as well as some false positives due to the use of image data only.

We have found that the more stringent criteria used to produce the automatic output for rutting of the verge gives some agreement with the reference. It is felt that the automatic outputs for overriding can at the very least be used as a filter to identify potential lengths of overriding which can be investigated further, whilst the identification of rutting of the verge gives a more positive indication of a severe overriding defect.

8.6.2 Edge Stepping

An output for edge stepping, as proposed in section 8.5.2 was examined. This calculates the step in the profile found where the image located road edge is identified. This differs from the full step edge locator in that the aim is not to locate a profile step feature, the aim is to continuously report any step height, which can take any value as a threshold is not applied. This value can then be associated with image detected overriding or can be used to look at edge stepping itself as a defect.

In line with the initial methods, edge stepping is reported as the percentage (by length) of the road edge with an edge step of 20 to 50mm downwards (level 1) and greater than 50mm downwards (level 2). Although this is an equivalent output to the initial methods, the enhanced methods offer the potential for improved accuracy due to the more accurate edge location and improved coverage. Furthermore, for the enhanced methods, the step height is calculated using the detailed profile measurements adjacent to the step edge, whereas the initial methods rely on lower resolution measurements obtained over the verge/road interface.

The reference and both initial and enhanced automatic edge step data are compared in Figure 45. Note that the reference data relates to the locations of steps identified in the manual analysis of HARRIS1 forward facing video data. It can be seen that the initial and enhanced methods produce broadly similar results. However, the enhanced method results align more precisely with the location of positive results within the reference data, indicating a small improvement, which has occurred alongside a significant reduction in false positives.

8.6.3 Potholes

We consider potholes at the road edge to be special cases of localised edge stepping. Hence, to report potholes we assess each location where stepping in the profile data occurs at a transverse location to the left of the position at which the road edge was located in the image data. Due to the range of features observed at the road edge, the features identified by this method are not limited to potholes. Hence, if the road edge has an unbroken surface (i.e. the surface loss associated with a pothole has not occurred) but a large a step or bowl shape is present (deformation), then a pothole may be reported.

Potholes are reported as the percentage of each reporting length over which the algorithms have identified pothole-like features, as shown in Figure 46 for the Hampshire rural test section. The reference data was derived from the manual identification of pothole features in the HARRIS2 image...
and profile data. Although there is some agreement in the identification of defects at 100m, there is a length of false positive reporting of potholes between 200m and 300m. Checking of the reference data showed that this length does not contain potholes. However, a significant slope exists at the edge of the road. Such a ‘deformation’ feature may not be identified in the manual assessment as the surface appears intact and the profile only shows a steep cross fall near the edge.

It was found that the manual analysis is much more sensitive to reporting potholes when these are clearly visible in the images such as evidence of a broken surface, and only the more obvious defects are identified. However the automatic method is biased to features identified within the profile shape. Therefore when the whole Hampshire was examined very few potholes were recorded in the manual reference dataset – implying a high false positive rate for the proposed automated technique.

![Figure 45: Video reference, initial and enhanced results for Edge Stepping for the Hampshire dataset.](image)

![Figure 46: Pothole reporting for the Hampshire rural test section.](image)
These “false positives” were investigated further, as shown in the following examples containing the image data taken over the road edge. Superimposed on the images is the road edge detected in the image data (green line), the verge/overriding edge detected in the image data (white line), the road (step) edge detected in the transverse profile data (blue line) and the image and profile step combined road edge (orange line). Note that the road edge detected in the images is usually co-incident with the combined edge, and sometimes coincident with the verge/overriding edge. The identification of potholes is shown by a red bar on the right side of the figures.

A number of cases were found where a defect within the road surface did not take on the typical appearance of a pothole, and would be unlikely to be reported as a pothole by the manual analysis. (e.g. Figure 47). However, the pavement is defective, but the defect may be termed ‘edge erosion’. At the current stage of development, it seems logical to report such defects by the pothole/surface deformation method provided the defect is within the located road edge boundary.

![Figure 47: Pothole detection at road edge.](image)

![Figure 48: Road step edge detected as a pothole.](image)

A significant number of examples were found where there was a step at the road edge that was correctly identified, but the road edge in the image data was incorrectly identified to the left of the step edge. This occurs when there is little contrast in colour between the road surface and the dirt verge (Figure 48). Given the assumptions of pothole detection, this generates a false positive report – the defect is actually a rutted verge, but we obtain a report of a pothole.

In summary, the “pothole” detection algorithm, which makes direct use of the image and profile derived edge locations, has been found to work when examining the data for short lengths where the detection of particular defects can be seen. However the performance is less convincing in comparison with various sources of reference data. It has been determined that this has been in part due to the way the reference data has been produced in comparison to the wider range of defects which could potentially trigger a positive response from the automatic output. It is felt that this method does provide an indication of where the surface contains severe shape defects, and could be used with minimal further development. However the method could also be augmented by improvements to the methods for examining the profile shape and utilisation of the detected road edge location.
8.6.4 Raised Kerbs

In section in 8.5.4 a method was proposed to identify the presence of raised kerbs, identified over lengths of 0.1m. For analysis it is proposed that the presence of raised kerbs be reported as a percentage of each ten metre reporting length. The results of the kerb indicator for the Hampshire rural and urban test sections are shown in Figure 49. The kerb detection method has reported the presence of raised kerbs on the rural site where present. However, only a proportion of the kerbing has been identified. On the urban site there is good agreement with the reference, and no apparent false positives (some lengths of kerb are not detected because of missing transverse profile data, see section in 8.5.4). It can be seen that, frequently, almost 100% of length where a kerb is present has been identified. This higher level of performance reflects the fact that the kerbs on the urban site were not obscured by vegetation. There remains some drops in the percentage of kerbing reported within the kerbed lengths, the primary reason for this is that dropped kerbs with smaller up-stand are not detected by this method, but have sometimes been reported by the manual assessment which noted profile steps using the judgement of the assessor but did not apply a strict threshold to the step height.

![Figure 49: Indication of raised kerbs, shown with reference and profile availability](image)

It is apparent from these two sites that, although the method has strong potential, it does not give a clear and definite indication of whether a particular point along a road has a raised kerb. However the method appears to be capable of highlighting broad lengths that are likely to be kerbed. The method may be sufficient for use when interpreting other data such as rutting or edge condition, to filter lengths where the report of deterioration would be in doubt if the edge has a raised kerb. The method could also be modified to evaluate kerb upstand.

The results of the kerb indicator are plotted for the first 10km of the Hampshire dataset in Figure 50. The output is shown against the kerbs that have been noted by a manual analysis of the HARRIS forward facing video. The plot indicates which reporting lengths are indicated as greater than five percent kerbed by the reference and automatic outputs. This threshold gives an indication of the agreement between lengths containing kerbing and removes a number of positive responses resulting from isolated false positive identification of kerbing at the 0.1m evaluation interval used by the method (8.5.4).

The plot shows again that the percentage correctly reported as kerbed by the automatic method is quite variable with but that there is some location agreement between a number of the non zero responses from the automatic indicator and locations recorded as kerbed from the video. However it is also apparent that there is a significant number of kerbed sections that are not identified and there are a smaller number of false positive indications of raised kerbs.
8.6.5 Surfaced Verge

The presence of a ‘surfaced’ verge is reported as the proportion of the length where a surface is present across the full width of the survey (e.g. a road surface or footway has been identified up to the left edge of the image). The automatic output indicating a surfaced verge was obtained for the 38km Hampshire test dataset and compared to locations containing a paved surface beside the survey lane identified from manual analysis of forward facing video. However the performance achieved for the test sites (section 8.5.3) is not reflected over the larger dataset and it was found that the presence of fully surfaced images is over reported when compared to the reference.

The results for part of the Hampshire dataset are shown in Figure 51. It is apparent that a greater proportion of the survey is reported to contain a surfaced verge by the automated method than by the reference but that there is some similarity. One aspect of the results is that there are sections where the automatic method gives a high number of false positives and sections where it does not. This can be seen before and after the 20.5km point in Figure 51. This seems to result from the impact of driving line in urban areas or on wider roads which can reduce the coverage of the road edge, causing the downward facing images to only contain the road surface. However, the wider viewpoint of the forward facing video enables the manual assessor to identify surfaced verges even when this deviation occurred, which can result in a difference between the two results. Where the road narrows and contains an un-surfaced verge the method is likely to become more accurate as the likelihood of measuring over the verge is increased. It was identified that the Hampshire dataset contains a wider A class road from 15 to 18km, a rural B class road from 18km to 22km and a C class road from 22km onwards. This change in road class has coincided with a narrowing of the surveyed lane, which appears to be reflected by increased agreement with the reference data.

It can be seen that the surfaced verge identification works in some circumstances, but that it should be interpreted as an indication of the surfaces contained within the survey measurement width and not as an accurate inventory of the route surveyed. A potential benefit this output is in the initial highlighting of lengths where deviation in the driving line occurred (although other edge data (such as stepping) would be required to confirm this), or for identifying lengths where the lane is wider than can be measured and so we would not expect edge deterioration to be reported.
8.7 An Indicator for Edge Deterioration

Although the enhanced methods offer the potential for more detailed and more accurate assessment of individual defects, it is proposed that, as for the initial parameters, a single measure of edge deterioration would be the most appropriate starting point for identifying lengths in need of further investigation.

The proposed indicator, which follows the method proposed for the indicator for the initial parameters in section 7, combines the enhanced parameters for edge stepping, overriding and potholes (which indicates broken or deformed surface defects). The identification of fully surfaced images is incorporated in the identification of overriding, where this feature is relevant. For the current assessment we have not included kerb identification to filter the results due to uncertainty about its accuracy. Instead the kerb parameter can be used to provide additional information about the site when interpreting the results. If the accuracy can be improved, the kerb identification could be used to filter out supported road edges as appropriate.

The suggested indicator is designed to contain equivalent parameters to the indicator suggested for the initial methods. The methodology used to produce the indicator means that it is possible to ‘add-in’ further parameters indicating edge condition that cannot be directly compared to the current reference dataset or are not part of the focus of the current work. This means that in future the indicator could include methods made possible by the identification of the road edge within the data (i.e. edge cracking or further profile assessment).

With potholes, overriding and edge stepping reported as the percentage by length of the 10m reporting interval containing that defect, the indicator can be calculated as follows:

Enhanced Edge Indicator EEI = 0.5 * Potholes + 0.25 * Overriding + 0.25*Edge Stepping

It was decided not to include the more severe output ‘rutting of the verge’ in the indicator, as the trends in this measure often follow those obtained by combining the overriding and edge stepping parameters, and would therefore double up the influence of these parameters.

8.7.1 Performance

The values of the edge condition indicator are compared with reference values in Figure 52 for the rural test section of the dataset. Here the reference has been obtained by applying the formula for the indicator to the potholes, overriding and edge stepping detected manually in the HARRIS video and profile data. It can be seen that there is good agreement in the locations of high values between the automatic and reference methods, showing that on this site the automatic detection of edge deterioration is close to that found by the person viewing the data. Therefore, although examination of the individual defects in the above sections has highlighted cases where deterioration was either missed or falsely reported, when defects are combined the presence of edge deterioration is quite accurate.

![Figure 52: Automatic and manual edge deterioration indicators obtained on the rural test section](image-url)
Figure 53 compares the values of the enhanced edge indicator with the CVI scores and video reference indication of edge deterioration obtained on the Hampshire dataset used in the earlier assessment (section 7). It can be seen that the CVI reporting of edge deterioration is clustered around 20 to 30km, with little CVI edge deterioration reported on the remainder of the site. This probably shows the insensitivity of the CVI technique – reporting only where the edge deterioration is clearly visible. The automatic method also reports a higher density of deterioration over this length. The manual reference has greater sensitivity to the presence of small lengths of deterioration, as can be seen by the frequent localised reports of deterioration in the manual dataset. There is a high level of visual agreement between the manual and automatic reporting of edge deterioration at these locations.

It appears that the indicator can at the very least provide a robust filter to locate lengths of potential edge deterioration. The ‘visual’ agreement with the reference is better than that found when the constituent parameters used by the indicator were compared with reference values. A possible explanation for this is that each parameter is biased towards low false positives, at the expense of missing some deterioration. With several parameters combined in an indicator it is more likely that at least one parameter will have responded to a particular element of the edge deterioration, resulting in a positive response from the indicator. Additionally, although it does not include overriding, the CVI reference for edge deterioration has a more broad definition not limited to an individual defect type and therefore the possibility of agreement with this reference is increased.

![Figure 53: Edge Deterioration Indicator plotted with CVI and Video reference data](image)

It is appropriate to compare the results obtained with the enhanced indicator with those reported by the initial indicator over the same lengths of the network. In Section 7 we assessed the initial indicator over longer averaging lengths to reduced noise, and determine how well it could indicate the broad level of edge deterioration, as it was known that it lacked the ability to locate deterioration more precisely. In Figure 54 we compare the 1km averaging of both the initial and enhanced indicators to compare their performance in estimating the broad level of edge deterioration present on a site. The data has been normalised to give an average value of one for each series in order to allow comparison of the shape of each output. The plot shows that the enhanced indicator reflects the reference a little better than the initial indicator, but the improvement is less pronounced at this reporting level. The initial and enhanced indicators give the highest values in the area where edge deterioration is indicated by the reference.
Figure 54: Comparison of edge deterioration indicators averaged over 1km
9 Relative Benefits of Enhanced and Existing Techniques

A number of key questions relating to the performance and potential of the enhanced methods are discussed within this section.

9.1 Do the new methods offer higher level of performance?

Both the initial and the enhanced techniques rely on identifying the road edge location to determine the extent of edge deterioration. The edge is used to segment the image and/or profile data to leave data measured only from the road surface. The remaining (road) data is then processed appropriately to identify edge defects or such parameters as the ‘edge roughness’ or ‘absolute deviation of the first derivative’.

A manual assessment of the rural test section was carried out to determine how well the enhanced methods have identified the road edge, and how this compares to the initial methods. The manual analysis traced the road edge as it appeared in the HARRIS2 image and profile data using a fine grid placed over the data, filling in the grid squares that contained the road edge. Where the position of the road edge was ambiguous, multiple grid squares were marked covering the region that could contain the road edge. Figure 55 plots (as the distance from the left edge of the image) the edge of the road surface as indicated by the initial, enhanced and the manual method.

The data shows that the initial method often identifies the road edge at a location several cm to the offside of the true road edge, which is probably desirable for reduced false reporting of edge deterioration. However, the enhanced methods have identified the road edge largely in agreement with the manual analysis, with a significant improvement over the initial method. Where a definite edge line is not clear even to a human observer, and a wider edge ‘zone’ is indicated by the manual analysis, the enhanced method generally manages to identify the edge within this zone. It is apparent that the use of colour image information enables the algorithms to identify the road edge more accurately than from the profile data alone (as used by the initial methods).

For both the initial and enhanced methods the identification of defects has relied on the successful location of the road edge. It follows that the more accurate location of the edge using the enhanced methods should result in improved assessment of edge deterioration.

The accuracy of the enhanced methods to indicate the presence of any edge deterioration has been tested by producing an indicator based upon the enhanced parameters, which could be directly compared to the initial methods edge deterioration indicator. The performance of the enhanced indicator is better than the initial indicator for network level identification of edge deterioration. However, the extra detail measured by the enhanced data collection equipment may not greatly improve on the ability of the initial methods to simply indicate whether there is any edge deterioration present.
9.2 Do Local Authorities need the detail?

Our assessment of the Initial Parameters found that these methods provide an indication of the general level of road edge condition and transverse deformation in a length of road, and show which areas of a given network are likely to be in better or worse condition than the rest of the network. The Initial Parameters can be combined to produce an overall Edge Deterioration Indicator. The use of this has been demonstrated on a number of roads.

However, the Initial Parameters are a network level tool, providing little information on the individual defects present. The enhanced methods, based on newer technologies, aim to provide more details on the type, severity and extent of deterioration, and to classify defects into overriding, stepping and pothole-like features. The enhanced methods combine detailed profile data with colour images to improve the road edge identification. This will also improve any subsequent processing, as it will avoid using data from the verge, which could degrade the results.

If the use of SCANNER data is only for network level investigation, and no “drilling down” into the data is required, then the initial methods should be appropriate. However, the adoption of enhanced measurement equipment and interpretation methods such as those proposed here will enable engineers to review the approximate intensities of specific defects at any location, which will improve planning and significantly add to the current capabilities of SCANNER as a condition assessment tool.

9.3 Does it offer potential for scheme level inspection?

As well as more accurately reflecting deterioration levels over short lengths, a further advantage of the enhanced methods is that they can capture more information regarding the defect type, giving a more accurate automatic indication of the specific problem and the repairs that would be necessary. Though the individual parameters are currently not reaching very high levels of accuracy, the outputs are more useful for scheme level assessment than those from the initial methods. Continued future development could improve the accuracy of individual parameters and add new outputs that could indicate additional defects.

In addition to these advantages, the information is there in the enhanced measurements for potentially more defect types to be added. It is felt that the methods proposed here do not reach the limit of what can be extracted and interpreted from the enhanced measurements, whereas with the existing SCANNER equipment we are reaching the limit of what can be interpreted.

9.4 Does the provision of more information really justify the cost of forcing an implementation now, or should we let the development take its course?

The availability of the enhanced data collection is key to improving upon the initial methods. The enhanced data gives much more information from which defects can both be determined more accurately and also the range of defects that can potentially be identified is increased. However, these methods cannot be implemented using the data provided by routine (SCANNER) measurement systems. Therefore their implementation would require that changes be made to existing systems.

Conversely, the advantage of the initial parameters is that they can be provided by most current survey vehicles with no requirement for further investment in equipment. Further, it is felt that the industry is still catching up with initial methods and that the performance of these in wider use in the industry needs to be established before rapid changes are made.

Therefore, it may be appropriate to introduce the enhanced methods in coming survey years as SCANNER survey equipment is replaced. It should be noted that the use of the enhanced methods does not imply that equipment will be more expensive, just that it is more up to date. A methodology for enabling delivery to engineers should be considered (e.g. in UKPMS).
9.5 What is the potential for incremental improvement – e.g. applying high resolution transverse profile data soon, colour image collection later?

Incremental improvement may be possible at the expense of not achieving the full gains in performance offered by the enhanced methods. The enhanced methods rely on a number of key attributes for the measurements – width, profile resolution, colour. It is not considered likely that we could detect the road edge from a greyscale image with the same accuracy. However an enhanced profile system alone will mean that any road edge containing a significant step can be found, as could profile defects within the road surface. Additionally, a paved verge or raised kerb could be identified in a different way, perhaps from a less sophisticated image and profile system, or from dedicated sensors. There may be scope for improvement of the initial methods through improved inventory data, which would rule out particular defects at each position or site.
10 Conclusions and Implications for SCANNER

10.1 Initial Parameters

The initial research projects into the detection of edge deterioration and the use of transverse profile data on local roads developed a set of Initial Parameters to estimate the level of deterioration of the road edge and the transverse profile of the pavement. These estimates are derived from an analysis of successive transverse profiles provided by existing SCANNER survey vehicles. They provide information on the edge roughness, edge stepping, variation in roughness across the road, transverse deformation of the pavement, and also provide enhanced rut measurements. These parameters were relatively untested. This work has carried out an assessment of the performance of the Initial Parameters and investigated how they should be used for condition assessment. We have investigated the behaviour of the parameters over a range of test sites located on the local road network, covering A, B, C and Unclassified roads leading to the following observations:

- When considered over 10m aggregation lengths there is a significant level of noise present in the values of the initial parameters. For comparison with reference data it was found appropriate to assess the parameters by finding the proportion of each 1km length over which the parameters reported values that were higher than the 95th percentile of the test data set. We have compared the parameters, considered in this way, with the results of CVI surveys and manual analysis of images.

- Assessment of the parameters related to edge deterioration has shown good agreement with the CVI and manual surveys. Although some disagreements were observed, the disagreements between the two reference datasets were similar to the disagreements between the Initial Parameters and the references, reflecting the difficulties in obtaining unambiguous reference datasets for the defects.

- It was found that the Edge Roughness and Transverse Variance parameters often gave high responses in the presence of any form of edge deterioration, but the Edge Stepping parameters tended to give high responses only in the presence of edge stepping.

- Through consideration of the behaviour and ranges of Initial Parameter values we have proposed an Edge Deterioration Indicator for use with the Initial Parameters. This combines individual values of the Initial Parameters over each reporting interval:

$$\text{Edge Deterioration} = W_y \text{edge roughness} + W_t \text{trans variance} + W_{E1} \text{step 1} + W_{E2} \text{step 2}$$

Where the values of ‘y’ are obtained using a thresholded scale derived from the range of values expected on the network. The recommended values for the weightings are:

- $W_y = 30$
- $W_t = 15$
- $W_{E1} = 25$
- $W_{E2} = 30$

- The indicator will deliver a value between 0 and 100 and is similar in principle to the RCI developed for use with SCANNER data. It is recommended that the Edge Deterioration Indicator be applied over lengths of 100m to balance the level of noise in the data with the delivered accuracy and desired granularity.

- The initial threshold values recommended for use with the Edge Deterioration Indicator (100m lengths) are:
  - $T_{\text{lower}} = 10$
  - $T_{\text{upper}} = 30$. 
Clearly it would be appropriate to revisit these threshold levels following further experience with the application of the Edge Deterioration Indicator on the network.

- Assessment of the values provided by the Edge Deterioration Indicator has shown reasonable agreement with the opinions of engineers, although some differences were observed. Furthermore, the overall trends in the levels reported by the Edge Deterioration Indicator within different road classes show good agreement with the trends reported by the CVI survey.

- Although the work has shown that the Initial Parameters have good potential for the detection of edge deterioration, it has been found that the algorithms may fail to locate the road edge, and this can effect, in particular, the reporting of edge stepping. We have shown that the use of methods to filter the data based on achieved coverage statistics will not provide significant benefits to accuracy. As a failure to measure the edge stepping could affect the level of the indicator, work has been carried out to improve the methods employed by the algorithms to detect the road edge. This aims to improve accuracy and improve coverage. Enhanced algorithms are defined in Appendix B and Appendix C. Nevertheless it is also recommended that consideration be given to methods to monitor coverage, such as guidelines for operators to consider the driving line taken during a survey.

- The assessment of the transverse profile parameters has shown good agreement between cleaned rut depth and the standard rut depth, indicating that the cleaning process is not introducing unexpected behaviour into the reported data on these sites. The cleaned rut depth is often lower than the standard rut depth due to the removal of kerbs and verge features from the profile.

- Some unexpected behaviour in the cleaned rut depth measurements was observed, particularly on very narrow rural roads. This has given rise to higher levels of rutting than expected. Therefore work has been carried out to improve the methods employed by the algorithms to detect rutting. Enhanced algorithms are defined in Appendix B and Appendix C.

- The transverse profile deformation parameter (Absolute Deviation of the First Derivative) has been seen to be capable of identifying the presence of rutting and non-rutting transverse deformation.

- The assessment of the Initial Parameters has therefore shown that they are suitable for use on local roads. However, we have suggested a number of significant improvements to the algorithms, that should be implemented for future surveys. These improvements will not change the basic outputs of the Initial Parameters, but should improve accuracy and coverage.

10.2 Enhanced Methods

The second stage of this work has pursued the development of enhanced techniques for detecting and quantifying edge deterioration. Whereas the work on the Initial Parameters concentrated on typical SCANNER technology, this research has considered the use of technology that is currently available, but not necessarily used in current commercial measurement systems. The HARRIS2 system has been used to provide enhanced transverse profile and colour image data over a survey width of 4m, and in particular extending at least 1m to the nearside of the vehicle width, hence providing a better measure over the road edge. As well as the increased profile survey width, the transverse profile can be provided at a transverse spacing of 4mm by HARRIS2, this enhanced transverse profile data combined with the colour image data means that features such as kerbs, overriding and potholes are measured (Figure 56). In the development of enhanced techniques the work has aimed to enhance the assessment of defects currently provided by the initial parameters (e.g. accuracy and coverage), and also to identify further characteristics, currently not reported by these parameters.
We have drawn on existing work carried out by TRF for the development of image processing and transverse profile processing algorithms as a starting point for the identification of edge defects and undertaken an iterative research programme of testing and development to take the algorithms forward. The aim has been to develop algorithms to the point that they become viable for use in condition assessment, so that techniques to provide more accurate measurements of edge deterioration can be proposed for SCANNER surveys.

![Figure 56: HARRIS 2 Image and profile measurements over the road edge.](image)

The algorithms for the detection of edge deterioration draw strongly on their ability to identify the road edge from images and transverse profiles (red horizontal lines in Figure 56). This definition of the road edge is then processed using further algorithms to identify particular features. The work has concentrated on:

- Reporting the location of the road edge.
- Identifying and quantifying overriding.
- Identifying and quantifying edge stepping, particularly in conjunction with overriding.
- Identifying and quantifying potholes and similar features in the surface near the edge.
- Establishing if there is a “surfaced verge” i.e. when the nearside contains surfacing as may be present when there is a footway, driveway, side turning etc.
- Establishing if the edge is kerbed with an up-stand.

It has been found that, in general, the road edge is very well located by the algorithms, and to a much higher level of accuracy than that achieved by the initial methods. This high level of performance in edge location has arisen through the use of colour image processing, augmented by high resolution profile measurements, although the algorithms do not demand high image resolution. However, there are examples of poor performance that could be mitigated through further incremental improvements to the algorithms.

The road edge location has been used to identify lengths of overriding and the profile data has been able to indicate where this coincides with rutting of the verge. The performance has been found to be reasonable. A number of overridden lengths were missed, but the number of false positives was low.

The road edge location has also been used to report edge stepping. Two approaches were taken – reporting edge stepping using the profile data alone, and reporting the size of any step in the profile data at the location at which the road edge was identified in the image. Comparison between the edge stepping calculated using these methods and that reported by the initial methods, found a small increase in the accuracy of identifying significant stepping at the road edge.
Fusion of the image and profile data was used to identify pothole-like features at the road edge. At the current stage of development this output indicates the intensity of both potholes and severe transverse deformation. However, the reporting of potholes did not always agree with the reference, possibly because of differences in the way the defects are identified.

A high level of accuracy was obtained in the identification of surfaced or paved verges. This output proved useful for increasing the accuracy of the assessment of overriding, as a positive identification of a surfaced verge indicates that this defect should not be present.

Several methods to identify raised kerbed road edges were examined in order to obtain a measure for raised kerbs. This measure has made use of the detailed transverse profile and the image greyscale intensity values. Although the measure was unable to accurately detect all raised kerbs, the response over any length can be used to provide an indication of whether the length is generally kerbed.

An edge deterioration indicator has been proposed and tested. This development of this indicator followed the same methodology as that proposed above for the processing of the Initial Parameters. The values reported by this indicator were compared to the test data and to the values of the initial edge indicator. It was found that the enhanced indicator performed better in terms of assessing the broad level of edge deterioration, and for the assessment of edge deterioration at the local level.

When examining the results over short reporting intervals (10m) the enhanced methods showed a much greater ability to accurately identify the location of lengths with poor edge condition, as would be required when conducting an assessment at scheme level. The indicator gave fewer false positive responses, to the level that, at the very least, it would be suitable for targeting sites for further examination by an engineer.

A critical review has been undertaken of the relative benefits of the enhanced methods over the initial methods. There is little doubt that the enhanced methods offer significantly improved levels of performance over the initial methods. The enhanced methods, based on newer technologies, aim to provide more details on the type, severity and extent of deterioration, and to classify defects into overriding, stepping and pothole-like features.

However, these methods cannot be implemented using the data provided by routine (SCANNER) measurement systems. Herein lies the advantage of the initial parameters, in that they can be provided by most current survey vehicles with no requirement for further investment in equipment. Furthermore, it is felt that the industry is still catching up with the implementation of the initial methods, and that the performance of these in wider use needs to be established before rapid changes are made.

If the use of SCANNER data is only for network level investigation, and no “drilling down” into the data is required, then the initial methods should be appropriate. However, as SCANNER progresses more capability will be demanded by engineers, and in particular for scheme level assessment. Therefore, it may be appropriate to introduce the enhanced methods in coming survey years as SCANNER survey equipment is replaced. It should be noted that the use of the enhanced methods does not imply that equipment will be more expensive, just that it is more up to date. Methodologies should be considered that enable the enhanced techniques to be included in future SCANNER specifications, and to enable the delivery of the enhanced data to engineers (e.g. in UKPMS).

### 10.3 Implications for SCANNER Data Collection

#### 10.3.1 Initial Parameters

The work has demonstrated that the Initial Parameters are appropriate for network level assessment, without major alteration. The alterations which are proposed do not require changes to the data collection methods.
10.3.2 Enhanced Methods

The development of the enhanced methods has lead to the detection of features at the level of performance described above. In the development of these methods we have utilised a high resolution transverse profile and colour image collection system. If the requirements are to be defined as an end result specification then it would not be compulsory for survey contractors to implement such data collection equipment, but the data collection equipment that we have used to deliver these levels of performance has had the following capabilities:

- A colour image collection system that collects an image over a width of approx 4m and measures approx 1m beyond the physical width of the data collection vehicle.
- Colour images were collected with a resolution of 2mm, with a single image covering at least half the survey width. We have used uncompressed images, implying that a large capacity high speed data storage system is required on the vehicle. However, these images were reduced in resolution by a factor of 4 (8mm resolution) for image road edge detection, implying that the full resolution is not required. However, for other defect detection (e.g. crack detection) image processing algorithms typically require higher image resolutions.
- The effects of shadow should be minimised. We have found it necessary to utilise a powerful lighting system to allow the image data to be collected at traffic speed and reduce the effect of bright sunlight and shadow upon the images. Providing illumination over the road verge using powerful and non-enclosed lighting on the rear of the HARRIS 2 vehicle has been an issue. The addition of shielding has made the system compliant with the relevant vehicle lighting regulations however safety implications may occur for such vehicles operating on the public road.
- The transverse profile algorithms have relied on a system reporting a transverse profile measurement over a width equal to or exceeding that of the image collection system (at least 3.8m), with height value reported every 10mm in the transverse direction (with a 4mm transverse spacing possible). However, it is the opinion of the authors that a system reporting a transverse spacing of up to 25mm may achieve similar results.
- Transverse profile results for the identification of features were produced at a spacing of 100mm in the longitudinal direction. However, for the methods developed here a much smaller longitudinal data collection interval between profiles was used, which was then sampled at the 100mm interval according to data availability.
- The data collection systems must be fully integrated such that the image and profile data is transversely and longitudinally aligned to an accuracy of a few mm.
- Other points to consider for the enhanced methods:
  - It is desirable that the data collection systems can operate at traffic speed.
  - The HARRIS2 scanning laser reflectivity measurement produces a distinct response when measured over retro-reflective road markings. This measurement is reported as a single value at the location of each profile height measurement. This measurement has the potential to enhance the methods that we have developed, particularly to support the identification of kerbstones from the image data.
  - The enhanced methods here have not looked at longitudinal profile or even correction to the transverse profile for vehicle roll. It may be that a true 3D profile system will allow better shape assessment of the segmented road parts of the profile data.

As far as the authors are aware, the delivery of all of these capabilities will require developments to all SCANNER survey vehicles. The delivery of transverse profile data may be achievable using some SCANNER systems. However, the accuracy of the current SCANNER systems that may provide transverse profile at the level of resolution used in this work has not been assessed. No current SCANNER systems utilise colour image collection.
This does introduce the possibility of a staged introduction of the methods, using the transverse profile algorithms initially, and progressing to colour image collection at a later date. It is recommended that the implications of such an approach be reviewed.

10.3.3 Data Processing

The alterations to the Initial Parameters will be achieved through modifications to the specifications. These changes will not unduly affect algorithm speed of execution. DfT/Contractors must have processes in place to implement the changes successfully.

For the implementation of enhanced methods we envisage the requirements will be defined as an end result specification meeting the performance levels defined above. And therefore we can comment only on the data processing implementations should similar methods to those developed in this work be used.

The primary data processing requirements for the enhanced algorithms developed in this is that the raw data is delivered from both the image and transverse profile measurement systems after the survey, and that that data be very well aligned longitudinally and transversely (to within a few mm). Our implementation processes the images and transverse profiles separately to deliver the road edge locations. These are combined to derive the road edge and then further processing is carried out on this derived dataset (without further use of the raw image and profile data). The methods have been implemented on a standard Windows PC, but have not been fully optimised for performance. The implications of this are that the processing may require significant time after the completion of the survey (processing at a rate of less than 10km/h). It is felt that this speed should increase with optimisation.

10.3.4 Delivery and use of Data

We propose that a combined Edge Deterioration Indicator be used with the Initial Parameters to describe general edge deterioration. The definition of this is provided, and should be simple to implement in UKPMS. We propose that the same approach be used for the reporting of condition based on the enhanced methods. There would be the option to run initial and enhanced indicators in parallel, if desired, during implementation.

The initial indicator should be considered over 100m lengths to reduce noise. As the enhanced methods should provide better localised assessment, it may be more appropriate to consider this as a value reported over 10m lengths.

It is recommended that the combined Edge Deterioration Indicator derived from the Initial Parameters be the first value considered by the engineer, to target lengths of edge deterioration. Additional work would be required by the engineer to review the individual parameters contributing to this indicator and, due to the noise in the data, this examination may not provide significant further insight. In spite of this, the individual parameter values should be available if required, perhaps as a secondary dataset for use by the engineer after identifying lengths of concern.

A list of the potential outputs from the enhanced methods is given in Section 10.2. A number of these are in parallel to similar values provided by the Initial Parameters. It is proposed that the enhanced parameters be delivered in a similar way to the Initial Parameters to UKPMS.

For a staged implementation of enhanced methods SCANNER could offer options for the engineer to commission surveys that offer either the enhanced or initial edge deterioration parameters, with the engineer “seeing” a single indicator for edge deterioration derived from one or the other data source, but not having to be concerned with the details of the source. The engineer would, however, know that the enhanced approach is likely to give a more accurate measure of the condition with the capability of higher resolution. If this approach was followed it would be necessary, at the network level, to consider the effects of different sensitivities in each approach on the reporting of network condition (e.g. on KPIs).
Acknowledgements
The work described in this report was carried out in the Infrastructure & Environment Division of TRL Limited. The authors are grateful to Helen Viner who carried out the quality review and auditing of this report.

References


K Nesnas, S McRobbie, A Wright (2004). “Initial study and development of transverse profile analysis – TTS on local roads”, TRL Published Project Report PPR014


Appendix A. Summary of consultation findings

A.1 Sources

A number of sources of information have been utilised in the review:

**The Initial TTS Research.** Work was carried out by TRL and WS Atkins in 2004 to review the requirements for TTS surveys. TRL carried out initial consultations and assessment of typical TTS survey data to suggest what was required and the likely difficulties that might be encountered in the application of TTS data to condition assessment. The work of Atkins, in confirming the TTS requirements and establishing the base data, included consultations with a number of engineers and organisations to determine what measurable road condition characteristics were important for defining maintenance needs, road safety and the requirements of road users. This work took the form of a questionnaire followed by a workshop.

**Consultations with Local Authorities and Consultants.** We held discussions with a number of Local Authorities and consultants to assess their views on a range of issues relating to the collection of SCANNER data. The Authorities selected covered a range of geographical, urban and rural areas. All those approached were willing to participate in discussions and readily provided data for use in the project. Discussions took place late in 2004 and covered current and future aspects of data collection relevant to SCANNER, types of defects and the value of defects to local authority engineers. A list of those consulted in this stage of the project can be seen in Table 11.

<table>
<thead>
<tr>
<th>Organisation</th>
<th>Principal Contact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chris Britton Consultancy</td>
<td>Chris Spong</td>
</tr>
<tr>
<td>WDM Ltd Hampshire County Council</td>
<td>Chris Kennedy</td>
</tr>
<tr>
<td>Clive Griffiths</td>
<td>Joanna Edwards</td>
</tr>
<tr>
<td>Durham County Council</td>
<td>Gavin Bolton</td>
</tr>
<tr>
<td>Shropshire County Council</td>
<td>Danny Rawle</td>
</tr>
<tr>
<td>Leicestershire County Council</td>
<td>Helen Franklin</td>
</tr>
</tbody>
</table>

Table 11: Organisations involved in the consultation process.

**IAG members survey.** A questionnaire survey was carried out towards the end of 2004 by Halcrow to gain views of IAG members on BV(96), use of CVI and experience with SCANNER data.

A.2 Current Maintenance Practice

The consultation attempted to determine how current maintenance practices are driven and prioritised. In the discussions, it was apparent that maintenance is often carried out primarily for reasons of reducing the BVPI. However, the consultation has tried to look beyond this focus on BVPI, and concentrate on establishing the physical characteristics of any length of pavement which would highlight it for maintenance need, and has considered the levels of detail and information which would be required by the engineer in order to make maintenance decisions.
The consultation found that authorities currently collect condition information using several standard methods such as Coarse Visual Inspection (CVI), Detailed Visual Inspection (DVI), TTS, SCRIM and Deflectograph.

The use of the deflectograph is still widespread as it has been commonly used in previous years. Many engineers are comfortable with this method, and have used this with CVI to produce BV(96).

CVI is again a common method of condition measurement, which is often a walked survey, and is generally carried out on all A, B, C and 25% of U roads. DVI surveys are typically only carried out on footways.

Some authorities use CVI data to assist with maintenance planning. Authorities also use CVI for budget allocation, via the BVPI. However, different approaches are taken in the use of CVI data. For example, CVI may be used to provide BVPI as well as identifying lengths for treatment, or it may be used to identify lengths for more detailed investigation that are then surveyed using other methods. The maintenance programme in some authorities is driven almost entirely by CVI results.

Although CVI surveys are often viewed as a means to obtain condition data at a reasonable level of detail that is sufficient for maintenance planning, and to provide the facility to derive a BPVI, this survey method is not always used in this way. It was found that some authorities use CVI only to derive BVPI. To obtain the condition data to determine needs these authorities use in-house systems, such as HAMP in Hampshire and Leeds in Leeds. These surveys take the form of a visual inspection that deliver data in a way that is targeted to the individual authority’s maintenance assessment programme (for example Leeds gives a rough condition value for each street). These are generally walked surveys, often focussing on treatment requirements. Sometimes they are used to assess, in greater detail, bad sections that have been identified by safety and other routine inspections or local knowledge.

A.3 Using SCANNER Data to Determine Condition

The research programme is to pursue the development of methods to identify defects on local authority roads, for use by the engineer to determine the maintenance condition and prioritise treatments. If successful this could offer a replacement for the CVI and other surveys employed by local authorities as described in the preceding Section. However, to prioritise maintenance treatments with the new methods it will be necessary for the engineer to have suitable information regarding particular defects, and then have the facility to decide on how the presence and severity of these defects should be interpreted. Therefore we need to determine the defects of importance in the condition assessment and how they should be considered with regard to maintenance. A review of defects was therefore undertaken to determine the types of defect typically identified on local roads. Defects were assessed in terms of their importance in determining maintenance condition so that a position could be established with regard to prioritisation. In order to approach maintenance practice encompassing a wider viewpoint than basic engineering requirements (e.g. limited to structural assessment), DfT’s brief for this research work specified that pavement condition should considered in three categories: Safety, Functional level of service and Engineering Maintenance. TRL proposed that the Edge defects present on the pavement were relevant to each of these categories as shown in Table 12.

The list of defects and our proposals for how they should be allocated within the specified categories were discussed with highway engineers and consultants. During discussions it was found that Engineering Maintenance required clarification as maintenance performed in order to preserve the asset, as engineers otherwise considered all defects as requiring ‘engineering maintenance’. The defects were also assessed against the results of the previous work considered as part of this review. The consultation found that engineers do not currently consider defects or maintenance needs from this 3-perspective approach, and were instead mainly driven by a combination of BVPI considerations and Engineering Maintenance. However, once the details of the approach were explained to them the engineers found the approach to be reasonable, and agreed that it could provide a useful tool for assessing condition and for prioritising maintenance in a wider perspective.
The consultation noted some disagreements between our proposed categorisation of defects and the viewpoints of the engineers. For example, two local authorities suggested that transverse cracking affected Functional Level of Service, and that poor reinstatements and local subsidence should be considered within Engineering Maintenance. Camber was also suggested by one authority as an additional defect falling under the Safety and Functional Level of Service categories. However, in general it was found that engineers agreed that the defects identified in the list discussed with them was generally representative of the types of defects found on local roads. There was also general agreement to the allocation of defects to the categories shown in Table 12.

<table>
<thead>
<tr>
<th>DEFECT TYPE</th>
<th>DEFECT</th>
<th>Safety</th>
<th>Functional level of service</th>
<th>Engineering maintenance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Edge potholes</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>2</td>
<td>Overriding of the road edge</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>3</td>
<td>Edge defects</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lack of clear demarcation of edge by white lines</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

Table 12: Allocation of criteria for treatment for different defects

A.4 Viewpoints on Edge Defects

Specific points relating to edge defects that arose during the consultation process are noted below.

There was general agreement with regard to what constituted an edge defect – i.e. one which was mainly in the road edge area. Defects that extended into the main carriageway were considered as carriageway defects. However, the amount of defect extending into the carriageway that would be tolerated, before the edge defect became classified as a whole carriageway defect, was not well defined. Some of the responses suggested that any defect outside the 0.5m strip at the edge of the road would indicate a whole carriageway defect, while others seemed more flexible in their interpretations.

Edge defects were considered an issue for concern in both urban and rural areas. In urban areas, an important problem was water ponding at the road edge, resulting from aggregate loss at gaps between the road and the kerb or traffic calming features. In rural areas overriding of the road edge was a problem of note, although this is often not picked up in current visual surveys and in some cases, material is laid over the edge, overlapping the verge.

The underlying feeling in the Local Authority responses was that the most important factor was specifying the correct maintenance treatment. If there was a length of road where the edge was in need of repair, but the defects extended 0.75m across the carriageway, then a haunch repair would possibly be more appropriate than repairing the entire width of the carriageway. This may have implications for the interpretation of SCANNER data as there appear to be no specific or common rules applied by Local Authorities regarding the maintenance of edge defects.

A.5 Prioritisation of Defects

Subsequent to the above discussions, the participants were asked to help in establishing the importance of the individual defects, in terms of the priority that engineers would give to their treatment. This was not straightforward due to the many different types of roads common to the different authorities, and with different rankings possible for urban and rural roads, A, B, C and unclassified roads, and types of road user (e.g. cars and motorcycles).

However, when the areas of greatest agreement between authorities were identified it was found that:
For the *Engineering Maintenance category*, most authorities agreed that a combination of defects (e.g. potholes and cracking) indicated a priority need for treatment.

For the *Functional Level of Service*, many authorities stated that badly aligned ironwork and poor reinstatements were significant areas of concern because of the poor ride quality and noise issues associated with this. Excessive patching was also highlighted by engineers.

For the *Safety category* edge potholes, rutting and badly aligned ironwork were highlighted by engineers.

Table 13 summarises the defects identified as priority defects by those consulted.

**Table 13: Priority ranking of defects by criteria**

<table>
<thead>
<tr>
<th>Priority</th>
<th>Safety</th>
<th>Functional level of service</th>
<th>Engineering maintenance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Potholes (especially at the road edge)</td>
<td>Potholes</td>
<td>Wheel track cracking</td>
</tr>
<tr>
<td>2</td>
<td>Poor surface texture/skid resistance</td>
<td>Poor reinstatements</td>
<td>Potholes</td>
</tr>
<tr>
<td>3</td>
<td>Fattening up</td>
<td>Badly aligned ironwork / noise</td>
<td>Whole carriageway cracking</td>
</tr>
</tbody>
</table>
Appendix B. Revised Specification for Initial Parameters – Edge Deterioration

B.1 Introduction

1.1. This document describes the methods for assessing edge deterioration from SCANNER transverse profile measurements.

1.2. Three methods have been developed which make use of transverse profile information and may be used to indicate different aspects of edge deterioration. These are:
   - **Edge Roughness** - an indicator of the roughness of the road surface adjacent to the road edge.
   - **Road Edge Step** - a measure of any step down or up at the edge of the road surface onto the verge or onto a kerb.
   - **Transverse Variance Method** - a measure of the difference between the left and right half transverse variance values calculated from transverse profile data.

1.3. Each of these values is reported for a reporting length \( L \), typically 10m.

1.4. The key steps to obtain these values are is given below:
   - Measure, and store, the transverse profile data for the survey (but see Section B.10 regarding real-time processing)
   - Use the edge location method (see 3.1 regarding input data) to determine position of the edge of the road surface.
   - Calculate \( \text{‘R’} \), the parameter indicating severity of road edge roughness (Section B.6).
   - Calculate the step heights \( L_{SL1} \) and \( L_{SL2} \) (Section B.7).
   - Calculate \( T_{DIFFave} \), the indicator of transverse profile unevenness (Section B.8).
   - Calculate \( \text{‘U’} \), the percentage of profiles in length ‘L’ which covered the road edge (Section B.9).

1.5. The output values (\( R, L_{SL1}, L_{SL2}, T_{DIFFave} \) and \( U \)) will be added to UKPMS and can then be analysed separately, or in combination. An overall indicator of edge deterioration, calculated using these values, will be developed using rules and criteria to be determined.

1.6. The output values resulting from these methods, will become input values into UKPMS, where rules and criteria to determine the overall level of edge deterioration can be applied.

B.2 System requirements

2.1. The methods make use of transverse profile data as measured by a SCANNER compliant vehicle. However, the following are required for the algorithms to function properly:
   - The system shall be able to produce a series of transverse profiles at least every 100mm (as would be anticipated given the TTS requirement for rutting to be calculated at a longitudinal interval no greater than 100mm).
   - The raw transverse profile data, i.e. the height measurement from each measured transverse position, shall be available. Each transverse profile will contain a number of height measurements that specify the vertical position of points on the road surface (across the width of the survey) relative to a transverse datum line.
• The transverse position of each measurement point should be known (the transverse spacing of measurements will affect the performance of the algorithms, see 2.2).
• The survey width over which transverse profile measurements are provided shall be such that the system is able to measure beyond the (nearside) road edge when following a normal driving line on the majority of the non-principal road network.

2.2. The following are desirable characteristics for the measurement system, but not essential:
• High resolution transverse profile measurements are preferable (i.e. many points per transverse profile), as this is likely to improve the performance of the methods. The ‘Edge Roughness’ method will work best if more than three transverse profile points are contained within the region lying within 500mm of the road edge.
• Successive transverse profiles data may or may not be corrected by an inertial measurement system to correct for vehicle movement and hence provide heights above a fixed datum (so-called 3D profile). It is anticipated that, due to the nature of the algorithms, the use of uncorrected profile measurements will not greatly affect the results. However, it must be noted that the proposed algorithms and techniques have been tested using 3D profile measurements.

2.3. To operate in real time data buffering will be required in the measurement vehicle (see Section 9). Alternatively the methods may be implemented in post-processing.

B.3 Input Data
3.1. The following input data is required
• Methods detailed in sections B.6, B.7 and B.8 require the following information:
  The position of the road edge within the transverse profile obtained using the SCANNER transverse profile assessment method described in Appendix C. This is a floating point number, $e_n$, giving the transverse position of the road edge in mm. Where the edge of the road surface cannot be detected within the profile, the edge position is given as 0 (zero), the position of the nearside end sensor of the profile measurement system.
• Methods detailed in sections B.6 and B.7 require the following information:
  The measured transverse profiles, longitudinally spaced at intervals of D metres. For these algorithms, the transverse positions within the profile are measured from the first (nearside or leftmost) profile sensor position, which is located at 0.
• The following information is required by the method described in section B.8:
  The ‘cleaned’ transverse profile, the number of positions within the ‘cleaned’ transverse profile, $N$, and the cleaned transverse profile position index for the road edge location, $d_{max}$. These are generated for each transverse profile by the methods detailed in Appendix C.

B.4 Output parameters
4.1. The output values are:
• “$R$” – Edge roughness value (Ratio taking a value between 0 and 1 inclusive).
• “$L_{SL1}$” – Small step down at the road edge, percentage of reporting length.
• “$L_{SL2}$” – Large Step down at the road edge, percentage of reporting length.
• “$TDIFF_{ave}$” – Difference between the left and right transverse profile variance, units of mm$^2$.
• “$U$” – The proportion of profiles measuring over the road edge, percentage of reporting length.
B.5 Definitions

5.1. The following parameters are used in the algorithms described in this document.

- $y =$ measured transverse profile.
- $q =$ number of measurement positions within the measured transverse profile.
- $e_n =$ road edge position in mm from the nearside end of the measured transverse profile.
- $L =$ reporting length: should be parameterised, typically 10m.
- $D =$ longitudinal spacing between successive transverse profiles, typically 0.1mm, in accordance with the existing SCANNER specifications.
- $T_C =$ total number of transverse profiles in reporting length $L$.
- $V_{L\text{lim}} =$ Edge Roughness Longitudinal profile variance threshold.
- $\tilde{y} =$ ‘cleaned’ transverse profile.
- $N =$ number of positions within the ‘cleaned’ transverse profile, $\tilde{y}$.
- $d_{\text{max}} =$ position index of the road edge location within the cleaned transverse profile, $\tilde{y}$.
- $n =$ index for the transverse profiles within the survey length/section or reporting length, as applicable.
- $T_S =$ total number of transverse profiles in survey length OR section.
- $n_L =$ index for the reporting lengths (each of length $L$) within the survey length OR section, the first reporting length is referred to as $n_L=0$.
- $C_n =$ chainage of the $n^{th}$ profile within the survey length OR section.

B.6 Edge roughness

6.1. Figure 57 may aid in visualising the Edge Roughness measure. The following paragraphs describe the calculation of the Edge Roughness measure.

6.2. The methods described in the following paragraphs are known to work, however they calculate the 0.6m moving average longitudinal profile variance more often than is absolutely necessary. The requirement is that the 0.6m moving average longitudinal profile variance must be calculated for those points which are within the edge strip, extending from $e_n$ to $e_n+500$mm. Other methods of performing these calculations may be more efficient and are permitted, provided that they return the same values for $R$ as this method.
6.3. For the calculation of edge roughness we consider that, if successive transverse profiles were placed one after the other, each point across the successive transverse profiles could be extracted to obtain a series of approximations to the longitudinal profiles across the width of the pavement.

6.4. For a survey of length ‘Z’ metres, Let \( y_i(n) \) represent a particular transverse profile height measurement (height in mm), where \( i \) is the number of the point in the transverse profile, (0 being the nearside point) and \( n \) is the number of the transverse profile in the survey (starting from 0). The total number of points within each transverse profile is \( q \).

E.g. for a 100 metre survey with transverse profiles longitudinally spaced at 100mm intervals \((Z=100, L=10, D=0.1)\) and \( q \) points within each transverse profile we obtain \( q \) longitudinal profiles, with each longitudinal profile containing 1000 points. For measurement position 0 the longitudinal profile contains a series of 1000 profile heights spaced 100mm apart longitudinally which may be labelled, \( y_0(0), y_0(1), y_0(2), \ldots, y_0(999) \).

6.5. Count the total number of transverse profiles \( T_c \) within the reporting length \( L \).

6.6. Calculate the moving average longitudinal profile variance over a moving average length of approximately 0.6m for each longitudinal profile.

6.7. The moving average longitudinal profile variance at a particular position, \( y'_i(n) \) (moving average length approximately 0.6m, \( i \) is the transverse measurement position and \( n \) is the profile number), in units of mm\(^2\) is defined by:
where \( j \) is an index counter related to the particular transverse profile being considered, and \( M \) is related to the number of transverse profiles used in the moving average calculations, and varies as follows:

\[
M = \begin{cases} 
2 & \text{if } D > 0.12 \\
3 & \text{if } 0.09 \leq D < 0.12 \\
4 & \text{if } 0.07 \leq D < 0.09 \\
\text{int}(0.3/D) & \text{if } D \leq 0.07
\end{cases}
\]

6.8. The above process will generate approximately \( q \) data sets containing values spaced at a longitudinal separation, \( D \). Each value will represent the 0.6m moving average longitudinal profile variance along the path traced by each transverse profile point. Note that the 0.6m moving average longitudinal profile variance values defining the first and last 0.3m of the survey section length are set to zero, as indicated above, in 6.7.

6.9. The position of the road edge within the transverse profile, \( \epsilon_n \), obtained using the SCANNER transverse profile assessment method described in Appendix C is now applied to define a road edge strip with a left (nearside) position defined by the value of \( \epsilon_n \), and the right (offside) defined by the value of \( \epsilon_n + 500 \text{mm} \). See Figure 57.

6.10. Starting with transverse profile \( n=0 \), obtain the left and right transverse positions of the edge strip \( (\epsilon_0 \text{ and } \epsilon_0 + 500 \text{mm}) \).

- Transverse profile points located at positions \( \epsilon_0 \) and \( \epsilon_0 + 500 \text{mm} \) should be counted as lying within the edge strip.
- Calculate the number of transverse profile points lying within this strip, defined for profile 0 as \( \alpha_0 \).
- The number of transverse profile points lying within this strip, for profile \( n \) is defined as \( \alpha_n \).
- Calculate the number of transverse profile points lying within this strip that have a corresponding 0.6m moving average longitudinal profile variance greater than the threshold \( V_{\text{lim}} \) (recommended value 3mm\(^2\), but should be an adjustable parameter \( V_{\text{lim}} \)), defined as \( \beta_0 \), in profile 0.
- The number of transverse profile points lying within the edge strip with 0.6m moving average longitudinal profile variance levels greater than \( V_{\text{lim}} \), for profile \( n \) is defined as \( \beta_n \).

6.11. Repeat the calculations of paragraph 6.10 for each transverse profile until the evaluation has been carried out for the transverse profiles covering a longitudinal reporting length \( L \) (which shall have a default value \( L=10 \), but should be an adjustable parameter).

6.12. The number of transverse profile points within the edge strip, within reporting length \( L \), for which a variance value can be calculated) will be denoted as \( A \).

6.13. The number of transverse profile points with 0.6m moving average longitudinal profile variance greater than \( V_{\text{lim}} \), within the edge strip, within reporting length \( L \) will be denoted as \( B \).
6.14. For each reporting length (with numbering index \( n \)), Sum the values of \( \alpha_{n1}, \ldots, \alpha_{n2} \) and \( \beta_{n1}, \ldots, \beta_{n2} \) to obtain A and B respectively, where n1 and n2 are calculated as follows (M is defined in 6.7):

\[
\begin{align*}
n1 &= \min n \text{ for which } C_n > n_L L_{ave} \\
n2 &= \min n \text{ for which } C_n \leq (n_L + 1)L_{ave}
\end{align*}
\]

with the exceptions:

- if \( n_L = 0 \), then \( n1 = M \)
- if \( n_L = T_s D / L - 1 \), then \( n2 = T_s - M - 1 \)

where \( T_s D / L \) calculates the number of reporting lengths in the section.

6.15. Report the proportion of edge points, \( R \), above the variance threshold \( V_{Lim} \) for the length \( L \):

\[
R = \frac{B}{A}
\]

6.16. Repeat the calculations of paragraphs 6.10 to 6.15 for each longitudinal reporting length \( L \) in the survey, thereby reporting a value of \( R \) for each reporting length \( L \) in the entire survey, of length \( Z \).

**B.7 Road edge step**

![Figure 58: Calculation of the edge step height – measurements obtained from the transverse profile.](image)

(see method description, 90.2, for parameter definitions)

7.1. The following steps (7.2 to 7.16) should be carried out for each recorded transverse profile (of the \( n \) transverse profiles recorded in the survey).

**Evaluating the edge step height for each transverse profile**

7.2. For the calculation of the road edge step the following are defined:

- 7.2.1. \( x_0, x_1, x_2, \ldots, x_{q-1} \) describes the transverse position of each point in the transverse profile, measured from the leftmost point, 0, to the rightmost point \( q-1 \).
- 7.2.2. \( y_0, y_1, y_2, \ldots, y_{q-1} \) describes the profile height recorded at each point in the transverse profile.
7.2.3. \( \nu \) is the number of the first transverse profile point located to the left of, or at, the edge position \( e_n \).

7.2.4. \( R_1 \) is the number of the first transverse profile point located to the right of (and not equal to) the edge position \( e_n \).

7.2.5. \( R_2 \) is the number of the last (or rightmost) transverse profile point located to the left of or at a position 1m to the right of the position defined by \( e_n \) (i.e. at the position \( e_n + 1000 \text{mm} \)).

7.3. Obtain the least-squared best fit line for the transverse profile measurements recorded between position \( x_{R1} \) and position \( x_{R2} \) (shown in Figure 58 in green). The least squared fit will define a line \( Y = mx_i + c \) (where \( Y \) is the line height value at any transverse position \( x_i \), \( m \) is the gradient of the line and \( c \) is the value of \( Y \) at transverse position \( x_0 \)).

\[
m = \frac{XY - (R_2 - R_1 + 1)\overline{X}\overline{Y}}{X^2 - (R_2 - R_1 + 1)\overline{X}^2}, \quad c = \overline{Y} - M\overline{X}
\]

Where:
\[
XY = \sum_{i=R_1}^{i=R_2} x_i \cdot y_i, \quad X^2 = \sum_{i=R_1}^{i=R_2} x_i^2
\]
\[
\overline{Y} = \frac{1}{(R_2 - R_1 + 1)} \sum_{i=R_1}^{i=R_2} y_i, \quad \overline{X} = \frac{1}{(R_2 - R_1 + 1)} \sum_{i=R_1}^{i=R_2} x_i
\]

7.4. This best fit line should then be extrapolated from \( x_0 \) to \( x_{q-1} \).

7.5. The difference between the measured profile height at \( x_i \), and the height predicted by the best fit line is defined as \( s_i \).

7.6. For each point in the transverse profile from position \( x_0 \) to \( x_V \) (i.e. from the nearside of the transverse profile to the point immediately to the left of the edge position), calculate the values \( s_0 \) to \( s_V \) measured relative to the datum line \( Y \), defined above, \( s_i = y_i - \overline{Y}(x_i) \).

7.7. A positive step is defined as one where the measured profile height is greater than the profile height predicted by the best fit line.

7.8. A negative step is defined as one where the measured profile height is less than the profile height predicted by the best fit line.

7.9. Record the largest positive value (step up, \( s_{\text{Max}} \) (\( s_0 \) in Figure 58)) and largest negative value (step down, \( s_{\text{Min}} \) (\( s_2 \) in Figure 58)) from the dataset obtained in paragraph 7.6. If no positive step values of \( s_i \) occur, \( s_{\text{Max}} = 0 \), if no negative values of \( s_i \) occur, \( s_{\text{Min}} = 0 \).

7.10. As paragraph 7.9 evaluates the maximum and minimum values in the region to the left of the edge point, the value \( s_{\text{Max}} \) is the largest step upwards from the best fit line in the verge region of the profile, and the value \( s_{\text{Min}} \) is the largest step downwards from the best fit line in the verge region of the profile. \( s_{\text{Min}} \) will have a negative value if a downwards step exists from the road to the verge.

7.11. The transverse position where \( s_{\text{Max}} \) occurs is defined as \( p_{\text{Max}} \), and the position where \( s_{\text{Min}} \) occurs is defined as \( p_{\text{Min}} \). (In Figure 58 \( p_{\text{Max}} = x_0 \), \( p_{\text{Min}} = x_2 \))

7.12. If \( s_{\text{Max}} = 0 \), \( p_{\text{Max}} = 0 \). If \( s_{\text{Min}} = 0 \), \( p_{\text{Min}} = 0 \).

7.13. The step height, \( S \), is:

\[
S = \begin{cases} 
\text{Max if } p_{\text{Max}} > p_{\text{Min}} \text{ OR } S = \text{Max if } (p_{\text{Max}} = p_{\text{Min}} = 0 \text{ AND } s_{\text{Max}} > 0) \\
\text{Min if } p_{\text{Min}} > p_{\text{Max}} \text{ OR } S = \text{Min if } (p_{\text{Min}} = p_{\text{Max}} = 0 \text{ AND } s_{\text{Min}} < 0) \\
0 \text{ if } p_{\text{Min}} = p_{\text{Max}} = 0 \text{ AND } s_{\text{Max}} = s_{\text{Min}} = 0
\end{cases}
\]
Note: For any transverse profile where the road edge position, \( e_n \), is reported as 0, indicating that no edge was found within the profile \( S \) shall be given the value \( S=0 \).

**Reporting the edge step height**

7.14. Paragraphs 7.2 to 7.13 will generate \( T_C \) values of \( S \) for the survey, one for each transverse profile recorded in the survey, defined as \( S_0, S_1 \ldots S_{T_c-1} \).

7.15. To report the step heights define a longitudinal reporting length \( L \) (recommended value \( L=10m \), should be an adjustable parameter). Within each reporting length \( L \), evaluate the number of step heights with edge step values falling within the following bands:

- \( S_{L1} \): Number of downward steps of between -20mm and -50mm, including steps of -50mm, but excluding steps of -20mm exactly (-50mm ≤ \( S < -20mm \)).
- \( S_{L2} \): Number of downward steps greater than 50mm (where \( S < -50mm \)).

7.16. Within each reporting length \( n_L \), evaluate and report the percentage of the length \( L \) over which the step heights fell within the bands \( S_{L1} \) and \( S_{L2} \):

\[
L_{SL1} = 100 \cdot S_{L1} \cdot D / L \\
L_{SL2} = 100 \cdot S_{L2} \cdot D / L
\]

Where \( D \) is the longitudinal spacing of the transverse profiles.

**B.8 Transverse variance**

The transverse variance is obtained by the derivation of statistical parameters from individual ‘cleaned’ and resampled transverse profiles. The derivation of the resampled and cleaned profile data referred to in 8.1 is described further in Appendix C.

**Evaluating the left and right half transverse profile variances for each profile**

8.1. The method for obtaining the cleaned profile \( \tilde{y} \) is described in Appendix C. This array contains \( N \) re-sampled profile points \( \{ \tilde{y}_0, \tilde{y}_1, \ldots, \tilde{y}_{N-1} \} \). Data from points to the left of \( d_{max} \), \( \{ \tilde{y}_0, \tilde{y}_1, \ldots, \tilde{y}_{d_{max}-1} \} \), are set to 0 (zero).

The procedure ‘Slope and offset suppression’, defined in Appendix C, 10.3-10.5, should also be applied to the cleaned profile data \( \tilde{y} \) before proceeding with the transverse variance calculations.

8.2. The position of the road edge expressed as the re-sampled profile position index (described in Appendix C) is given as \( d_{max} \).

8.3. The variances of the profile heights within each half are calculated, and reported as the left and right half variance values \( T_L \) and \( T_R \). This involves the calculation of the average of the cleaned profile heights for each half, \( \bar{L} \) and \( \bar{R} \). The sample position where the split between the left and right halves occur is calculated as \( H \). These values are all calculated for each profile as follows:
\[ T_k = \left( \frac{1}{H - d_{\text{max}}} \right) \left( \sum_{j=d_{\text{max}}}^{H} (\tilde{y}_j - \bar{L})^2 - \frac{\left( \sum_{j=d_{\text{max}}}^{H} (\tilde{y}_j - \bar{L}) \right)^2}{H - d_{\text{max}} + 1} \right) \]

\[ T_R = \left( \frac{1}{N - H - 2} \right) \left[ \sum_{j=H+1}^{N-1} (\tilde{y}_j - \bar{R})^2 - \frac{\left( \sum_{j=H+1}^{N-1} (\tilde{y}_j - \bar{R}) \right)^2}{N - H - 1} \right] \]

where

\[ \bar{L} = \left( \frac{1}{H - d_{\text{max}} + 1} \right) \sum_{j=d_{\text{max}}}^{H} \tilde{y}_j \]

\[ \bar{R} = \left( \frac{1}{N - H - 1} \right) \sum_{j=H+1}^{N-1} \tilde{y}_j \]

and

\[ H = \text{int} \left( \frac{(N - 1) + d_{\text{max}}}{2} \right) \]

8.4. With the cleaned profile values contained within \( \tilde{y} \) in units of mm, the output profile variance values will be in the units of mm².

**Calculating the transverse variance difference measure for the reporting length**

8.5. Count the number, \( T_C \), of transverse profiles within the reporting length \( L \).

8.6. Calculate the mean average of the values of \( T_L \) from the reporting length \( L \).

\[ T_{\text{Lave}} = \left( \frac{1}{T_C} \right) \sum_{n=0}^{T_C-1} T_L(n) \]

8.7. Calculate the mean average of the values of \( T_R \) from the reporting length \( L \).

\[ T_{\text{Rave}} = \left( \frac{1}{T_C} \right) \sum_{n=0}^{T_C-1} T_R(n) \]

8.8. The average difference between the two halves of the profile for the reporting length can then be calculated as \( T_{\text{DIFFave}} = T_{\text{Lave}} - T_{\text{Rave}} \). This is the value reported from the method.

**B.9 Coverage**

9.1. The coverage value \( U \) shall be evaluated for each reporting length \( L \), this value shall indicate the percentage of the length where the profiles have been measured over the edge of the road surface.

9.2. Profiles that do not measure past the edge of the road surface are indicated by a located road edge position value, \( e_n \), of zero. The value \( e_n \) is the road edge location found for each profile as described in section B.3.
9.3. Count the number of transverse profiles within reporting length $L$, $T_C$.

9.4. Count the number of transverse profiles within the reporting length $L$ which have a road edge position $e_{u}>0$, the valid coverage, $u$.

9.5. Calculate the value $U$ for each reporting length $L$ as $U = 100 \cdot (u/T_C)$. This value is a percentage.

9.6. It is suggested that the calculation of this parameter can be incorporated into the calculation of the step height measurement described in section B.7.

**B.10 Processing**

10.1. The algorithms may be implemented either as a post-process on the stored transverse profile data, or as a real-time process.

10.2. The edge roughness algorithms cannot be applied to individual transverse profiles. The location of the road edge for each profile, which is used for all of the edge deterioration parameters, uses consecutive transverse profiles, as does the edge roughness measure.

10.3. In order to implement the algorithms in real time, buffering of data will be required.
Appendix C. Revised Specification for Initial Parameters – Transverse Profile

C.1 Introduction
1.1. This document outlines the methods that shall be employed for determining the position of the edge of the carriageway, and for assessing the transverse profile of the pavement, based on data collected during machine based condition surveys on the non-Principal Road Network.

C.2 System Requirements
2.1. The methods make use of transverse profile data as measured by a SCANNER compliant vehicle.
2.2. The minimum requirements for the measurement system are:
   • Transverse profile point spacing: \( \leq 300\text{mm} \).
   • Number of transverse profile points: \( \geq 20 \).
   • The system shall be able to produce a series of transverse profiles at least every 100mm (as would be anticipated given the TTS requirement for rutting to be calculated at a longitudinal interval no greater than 100mm).
2.2. The system used to implement the algorithms must be capable of: storing transverse profile data in a buffer (if processing in real time), or storing the transverse profile to a suitable medium, if post-processing.

C.3 Input Data
3.2. The following input data is required
   • The measured transverse profile, longitudinally spaced at intervals of D metres.
   • The longitudinal averaging length \( L_{\text{ave}} \).
   • Raw transverse profiles.
   • The transverse spacing of measurement points, the total number of measurement points, the transverse positions of measurement points.

C.4 Output Parameters
4.1. The outputs from the algorithms are:
   • The location of the edge of the road as found in resampled transverse profile \( n \), reported as \( e_n \), the distance from first sensor position (mm).
   • The value of the absolute deviation of the 1st derivative of transverse profile data noted as \( \text{DevFD}_{\text{ave}} \). This value is calculated for the whole transverse profile.
   • \( \text{DevFD}_{\text{NS}}_{\text{ave}} \) is the absolute deviation of the 1st derivative of the transverse profile in the nearside of the profile.
   • \( \text{DevFD}_{\text{OS}}_{\text{ave}} \) is the absolute deviation of the 1st derivative of the transverse profile in the offside of the profile.
   • \( \text{RutNS}_{\text{ave}} \) is the average value of the nearside rut depth in the cleaned transverse profiles in reporting length \( L \).
   • \( \text{RutOS}_{\text{ave}} \) is the average value of the offside rut depth in the cleaned transverse profiles in reporting length \( L \).
C.5 Definitions

5.1 The following definitions are used in the definitions of the algorithms described herein:

- Transverse profile data points are defined as starting from 0, which is the first measurement point at the extreme nearside (left) of the profile.
- \( y = \) individual recorded (original) transverse profile.
- \( x_i = \) measurement point position.
- \( q = \) number of data points in the measured transverse profile.
- \( h = \) transverse sampling interval in the measured transverse profile data, \( h = x_i - x_{i-1} \). The value of \( h \) may vary between laser positions.
- \( \tilde{y} = \) resampled individual transverse profile.
- \( \tilde{x}_i = \) position of the resampled point.
- \( N = \) number of data points in the resampled profile.
- \( t = \) transverse sampling interval in the re-sampled transverse profile data, \( t = \tilde{x}_i - \tilde{x}_{i-1} \): this should be parameterised, recommended default value 25mm.
- \( q_L = \) number of points to include in moving average calculations from the left of current point in \( y \).
- \( q_R = \) number of points to include in moving average calculations from the right of current point in \( y \).
- \( L_{\text{ave}} = \) Averaging Length: parameterised, recommended default value 1m.
- \( \tilde{y} = \) Averaged (best) re-sampled transverse profile in length \( L_{\text{ave}} \).
- \( \tilde{y}^{(1)} = \) \( 1^{\text{st}} \) derivative of the averaged (best) re-sampled Transverse profile.
- \( \tilde{y}^{(2)} = \) \( 2^{nd} \) derivative of the averaged (best) re-sampled Transverse profile.
- \( D = \) longitudinal spacing between successive transverse profiles, typically 0.1m, in accordance with the existing TTS specifications.
- \( L = \) reporting length: parameterised, recommended default value 10m.
- \( T_C = \) total number of transverse profiles in reporting length \( L \) (\( T_C = L/D \)).
- \( n = \) index for the transverse profiles within the survey length/section or reporting length, as applicable.
- \( T_S = \) total number of transverse profiles in survey length OR section.
- \( n_A = \) index for the \( L_{\text{ave}} \) averaging lengths within the survey length OR section.
- \( C_n = \) chainage of the \( n^{\text{th}} \) profile within the survey length OR section.

C.6 Overview

6.1. The key stages are summarised in the following paragraphs.

6.2. Transverse Profile “Cleaning and Road Edge Identification

- Smooth and resample the transverse profile data;
- Calculate the “best transverse profiles” defining the representative shape of the resampled transverse profiles within the averaging length, with points to the left of the road edge removed;
6.3. Transverse Profile Assessment

- Correlate individual resampled transverse profiles with the “best transverse profiles” to locate the edge of road in the individual resampled transverse profiles;
- Remove non-road features from resampled transverse profiles – this produces the “cleaned” transverse profile;

C.7 Transverse Profile “Cleaning” and Road Edge Identification

7.1. The following paragraphs describe the method for locating the road edge and removing non-road features from the transverse profile.

7.2. The noise in each transverse profile is removed by applying a moving average in the transverse direction, as appropriate (Sections 9.1 and 9.2).
7.3. Each transverse profile is re-sampled using a cubic spline algorithm (Sections 9.4 to 9.7) to provide transverse profiles with points spaced (transversely) at a distance of 25mm.

7.4. A longitudinal averaging length ($L_{ave}$) is defined. All transverse profiles within this averaging length are used to calculate the “best transverse profile” (as seen in Figure 59). This “best transverse profile” is the average (mean) of all the individual transverse profiles contained in the averaging length (Section 9.9 - 9.12).

7.5. The position of the edge of the road ($e_{BP}$) is calculated in the “best transverse profile” (Section 9.13 - 9.16).

7.6. Having located the road edge in the “best transverse profile”, each individual transverse profile within the averaging length is correlated with the “best transverse profile”. This correlation is performed by comparing the “best transverse profile” with each individual transverse profile and by shifting the “best transverse profile” with respect to the transverse profile. This determines the size and direction of the shift required for each transverse profile to obtain the optimum correlation (Section 9.17 - 9.25).

7.7. The position of the edge of the road in each individual transverse profile ($e_n$) is found using the size and direction of the shift established in step 7.6 above (Section 9.29 - 9.31). Data at this point, or to the left of the edge location is defined as being off the road (verge, kerb, etc.), data from the right of this point is defined as being on the road.

7.8. Data which is deemed to be recorded from off the road is excluded from subsequent transverse profile analyses.

7.9. The “cleaning” process is summarised in Figure 60.
Main input parameters:
Matrix of transverse profiles
Averaging length

1. Resample profiles
2. For each averaging length
   - Calculate average profile
   - Smooth the average profile
3. For each transverse profile
   - Correlate transverse profile
   - Compute maximum shift & edge position

Figure 60: Flow chart of the cleaning algorithm
C.8 Transverse profile assessment

8.1. The transverse profile assessment is carried out for each transverse profile, but is applied only to the part of the profile defined to have been recorded over the road. This assessment is based on the absolute deviation of the 1st derivative of the transverse profile. The following paragraphs describe the process for the assessment of the transverse profile data.

8.2. The offset and slope are found and removed from the transverse profile (Section 10.3 - 10.5).

8.3. The first derivative of the transverse profile data (minus the slope and offset) is calculated (Section 10.6).

8.4. The absolute deviation of the first derivative of each transverse profile (minus the slope and offset) is calculated (Section 10.7 - 10.9).

8.5. A reporting length L is defined. The mean value of the absolute deviation of the first derivative is calculated over the length L (Section 12.1).

8.6. The procedure is summarised in Figure 61.

8.7. The entire procedure can be applied to the full survey length, OR separately to each section within the survey. This is implementation specific and should be taken into account in the comparison of results for purposes such as Auditing.

![Figure 61: steps to follow during the transverse profile assessment process.](image-url)
C.9 Details of edge detection and transverse profile cleaning algorithm

9.0 For each transverse profile within the survey, the lowest profile height should be found. This value should be subtracted from all of the profile heights y_i within the profile. From points 9.1 onwards within this specification document, reference to ‘y’ (‘individual (recorded) transverse profile data’) refers to profile data that has been offset as specified in this paragraph.

\[ y_i = y_i - \min(y_0, ..., y_{q-1}), \quad i = 0, ..., q - 1 \]

The original profiles should be retained for use with the ‘Edge Roughness’ and ‘Road Edge Step’ algorithms specified in Appendix B.

Smoothing the transverse profile

9.1. Smoothing of the transverse profile should be carried out when the transverse spacing of the measured points in the transverse profile is lower than t. Smoothing the transverse profile is intended to remove noise from the transverse profiles.

9.2. To smooth the transverse profile a moving average filter of length 2t is used. This method uses a moving average window to model a data point as the average of q_Li points on the left of the data point and q_Ri points on the right of each data point as:

\[ g_i = \frac{1}{1 + q_{Li} + q_{Ri}} \sum_{j-i}^{i+q_{Li}} y_j \]

where q_{Li} and q_{Ri} should be calculated for the i^{th} transverse position as follows:

\[ q_{Li} = \max \Delta \text{satisfying conditions } x_{j-\Delta} \geq 0 \quad \text{and} \quad x_{j-\Delta} \geq x_i - t \]

\[ q_{Ri} = \max \Delta \text{satisfying conditions } x_{i+\Delta} < q \quad \text{and} \quad x_{i+\Delta} \leq x_i + t \]

9.3. If smoothing of the transverse profile data takes place as described in 9.2, then each value of y_i in subsequent analyses is replaced with the corresponding value of g_i.

Resampling the data

9.4. Each transverse profile is resampled in order to create a uniform sampling interval. The resampling of data is performed using a cubic spline algorithm.

9.5. If q is the number of data points in a transverse profile, \((x_i, y_i)\) is a set of data points comprising an individual transverse profile, the cubic spline is applied as follows:

\[ \sigma_i = \frac{\sigma_{i-1}}{6} h_{j-1} + \frac{\sigma_{i}}{3} (h_i + h_{j-1}) + \frac{\sigma_{i+1}}{6} h_i = \frac{1}{h_i} (y_{i+1} - y_i) - \frac{1}{h_{i-1}} (y_i - y_{i-1}) \quad \text{with } i=1,2,3,...,q-2 \]

where \( h_i = x_{i+1} - x_i \) is the spacing between two adjacent profile points. \( \sigma_i \) is the second derivative of the profile at \( i \). The second derivatives are calculated in order to ensure 2\(^{nd}\) order continuity.

9.6. The equation above requires boundary conditions which are the actual transverse profile height at points \( i=0 \) and \( i=q-1 \). At these points the second derivative \( \sigma \) is assumed to be equal to zero.

9.7. The equation above (in 9.5) defining a set of algebraic equations are solved for unknown value \( \sigma_i \).

The algorithm recommended for solving a tri-diagonal matrix is given in C.13.

9.8. The resampled profile defined by \( (\tilde{x}_j, \tilde{y}_j) \) is calculated, by computing the following coefficients:

\[ a_i = (\sigma_{i+1} - \sigma_i)/6h_i \]

\[ b_i = \sigma_i/2 \]
\[ c_i = \left( \frac{(y_{i+1} - y_i)}{h_i} \right) - \left( \frac{(\sigma_{i+1} + 2\sigma_i)h_i}{6} \right) \]

\[ d_i = y_j \]

with \( i = 0, 1, 2, \ldots, q-2 \) and \( h_i = x_{i+1} - x_i \) as in 9.5.

Then the resampled profile is calculated as:

\[ \tilde{y}_j = \left( \frac{a_j(\tilde{x}_j - x_i) + b_j(\tilde{x}_j - x_i) + c_j(\tilde{x}_j - x_i) + d_j}{j} \right), \]

where \( j \) is an index, representing the points in the resampled profile, \( j=0,1,2,3,\ldots,N-1 \), where the appropriate value for \( i \) is dependant upon each resampling position \( x_j \), for each position \( i \) should be taken as the largest \( i \) for which \( x_i \leq x_j \).

**Note:** Sample code is available in C, demonstrating the iterative procedures to be followed in order to resample the transverse profile using the cubic spline.

### Average profile

9.9. The average transverse profile is calculated from the arithmetic mean of all the re-sampled transverse profiles within the averaging length, \( L_{ave} \). Within a whole survey OR a survey section, consecutive \( L_{ave} \) averaging lengths are indexed from the start of the survey by \( n_A \), with \( n_A=0,1,2,\ldots,TSD/L_{ave}-1 \).

9.10. The first and last profiles within each \( L_{ave} \) averaging length, termed \( n1 \) and \( n2 \), are identified, \( n1 = \min n \text{ for which } C_n > n_A L_{ave} \)

\[ n2 = \max n \text{ for which } C_n \leq (n_A + 1)L_{ave} \]

9.11. For a particular \( L_{ave} \) averaging length \( n_A \), The value of the average transverse profile height at transverse location \( i \) in the average transverse profile is calculated as follows:

\[ \bar{y}_i = \frac{1}{n2 - n1 + 1} \sum_{n=n1}^{n2} \tilde{y}(n), \]

where \( \tilde{y}(n) \) is the \( n^{th} \) individual resampled transverse profile within the survey.

9.12. The average transverse profile obtained is defined as the “best transverse profile” within the averaging length. The “best transverse profile” represents the shape of the road within the averaging length.

### Locating the Road Edge in the Average (best) transverse profile

9.13. The first and second derivatives of the best transverse profile are calculated as \( \frac{\Delta y}{\Delta x} \), and the second derivative is calculated as \( \frac{\Delta^2 y}{\Delta x^2} \), as follows:

\[ \hat{y} = \frac{\Delta \tilde{y}}{\Delta \tilde{x}} \Rightarrow \hat{y}_i = \frac{\tilde{y}_i - \tilde{y}_{i+1}}{t}, \quad i = 1, \ldots, N - 1 \]

\[ \ddot{y} = \frac{\Delta^2 \tilde{y}}{\Delta \tilde{x}^2} \Rightarrow \ddot{y}_i = \frac{\hat{y}_i - \hat{y}_{i+1}}{t}, \quad i = 2, \ldots, N - 1 \]

\[ \dddot{y}_0 = 0, \hat{y}_0 = 0 \text{ and } \hat{y}_1 = 0. \]

9.14. The first and second derivatives are used to locate the road edge. The sign of the second derivative at the location where the first derivative tends to zero is used to determine the nature of the kerb / feature (whether it is the top or bottom of a feature). Depending on the type of the curvature the algorithm searches for a minimum or a maximum. The minimum will indicate the top of a kerb, or a rutting feature, and the maximum will indicate the bottom of a kerb, or rutting feature.
9.15. The algorithm distinguishes between the descending step of a kerb and the one of a rut by calculating the ratio between the maximum 2nd derivative in the left third of the profile according to the procedures below, and the maximum 2nd derivative in the right third of the profile. The ratio is calculated as the absolute value of the larger of these two maximum second derivatives divided by the smaller value. This ratio is then compared to a threshold r in order to determine how the road edge location is selected for each profile. A ratio of r=5 is recommended for the rut calculations, but this value should be parameterised.

9.16. The edge is therefore located as follows:

- Define the leftmost point in the transverse profile as position p_0.
- Check the sign of the first derivative at p_6 (the sign of \( \dot{y}_6 \)), the fourth point on the resampled transverse profile.
- Find the first position in the interval p_6,…,p_{N/6-1}, where the first derivative \( \dot{y} \) is of the opposite sign to that found at p_6 (above). Let the preceding point be p_a. If the first derivative does not change its sign in the interval, then p_a is set equal to the location of the minimum value for p_6>0 and to the location of the maximum value for p_6<0.
- For locating minimum and maximum derivative values below, a minimum absolute value Q is applied so that derivative values of lesser magnitudes are ignored. The value of Q=0.00025mm\(^{-1}\) should be used.
- Find the sign of the second derivative of the transverse profile at position p_a.
  - If the second derivative at p_a is negative:
    - The minimum second derivative with a value lower than -Q occurring over the length N/3 (from p_2 to p_{N/3}) is looked for.
    - Define p_b as the position at which the minimum second derivative \( \ddot{y} \) with a value lower than -Q (from p_2 to p_{N/3}) occurs. If such a minimum is not found, p_b=0.
    - The maximum second derivative \( \ddot{y} \) with value higher than Q is looked for (to the right of p_b) between position p_b and p_{(N/3)}.
    - Let the position at which the maximum second derivative with value higher than Q (between position p_b and p_{(N/3)}) occurs be p_c. If such a maximum is not found, p_c=0 and Q is used for the ratio calculation described in 9.15.
    - Find the maximum second derivative in the right third of the profile, between position p_{(2N/3)} and p_{N}, with value higher than Q. If such a maximum is not found, Q is used for the ratio calculation described in 9.15.
    - Calculate the ratio between maximum second derivatives as per 9.15.
    - If the ratio is lower than or equal to r (defined in 9.15):
      - If \( p_{a} \geq 400/t \), set \( p_{a} = (400/t)-1 \).
      - Calculate slope as:
        \[
        \text{slope} = \frac{|\ddot{y}(6) - \ddot{y}(0)|}{6t}
        \]
        ( Ensuring t and \( \ddot{y} \) are expressed in the same units.)
      - The edge position \( e_{BP} \) is calculated as:
        - If \( \text{slope} < 0.11 \), \( e_{BP} = \) the smaller of \( p_a \) and \( p_b \).
        - If \( \text{slope} \geq 0.11 \), \( e_{BP} = p_a \).
      - If the ratio is greater than r the edge position \( e_{BP} \) is the greater of \( p_a \) and \( p_c \).
If the second derivative at \( p_a \) is positive:

- The maximum second derivative with value higher than \( Q \) occurring over the length \( N/3 \) (from \( p_2 \) to \( p_{N/3} \)) is looked for.
- Define \( p_d \) as the position at which the maximum second derivative with value higher than \( Q \) (from \( p_2 \) to \( p_{N/3} \)) occurs. If such a maximum is not found, \( p_d = 0 \) and \( Q \) is used for the ratio calculation described in 9.15.
- The minimum second derivative with value lower than \(-Q\) is looked for (to the right of \( p_d \)) between position \( p_d \) and \( p_{(N/3)} \).
- Let the position at which the minimum second derivative with value lower than \(-Q\) (between position \( p_d \) and \( p_{(N/3)} \)) occurs be \( p_e \). If such a minimum is not found, \( p_e = 0 \).
- Find the maximum second derivative in the right third of the profile, between position \( p_{(2N/3)} \) and \( p_N \), with value higher than \( Q \). If such a maximum is not found \( Q \) is used for the ratio calculation described in 9.15.
- Calculate the ratio between maximum second derivatives as per 9.15.
- If the ratio is lower than or equal to \( r \) (defined in 9.15)
  - If \( p_a \geq 400/t \), set \( p_a = (400/t) - 1 \).
  - The edge position \( e_{BP} \) is calculated as:
    - If \( p_a < 400/t \), \( e_{BP} = p_d \)
    - If \( p_a > 400/t \), \( e_{BP} \) is the smaller of \( p_d \) and \( p_e \)
- If the ratio is greater than \( r \), \( e_{BP} \) is defined as the greater of \( p_d \) and \( p_e \).
- If the second derivative at \( p_a \) is zero, \( e_{BP} = 0 \).
- If the calculated edge position, \( e_{BP} \), is not equal to zero then,
  - Define initial point \( ini \) as
    \[
    ini = \text{int} \left( \frac{e_{BP}}{\beta} \right) \times \beta
    \]
    where \( \beta = \text{int}(h/t) \) (calculated with \( h \) and \( t \) expressed in the same units).
    The edge position, \( e_{BP} \) is adjusted further as:
    - \( e_{BP} = ini + (m + 1) \times \beta \),
    if \( \text{slope} = \frac{\overline{y}(ini + (m + 1) \times \beta) - \overline{y}(ini + \beta m)}{\beta t} \) is greater than 0.11;
    calculated with \( \overline{y} \) and \( t \) expressed in the same units, with \( m \) varied between 0 and \( \text{int}(1000/h) \) when \( h \) is expressed in mm.
  - The ‘Best Transverse Profile’ now takes the value at \( p_{e_{BP}} \) as its first value:
    \[
    y_i = \overline{y}_{reg}, \quad i = 0, \ldots, N - e_{BP} - 1
    \]
    \[
    y_i = 0, \quad i = N - e_{BP}, \ldots, N - 1
    \]

**Locate the road edge in each transverse profile in the average length**

9.17. Once \( e_{BP} \), the road edge in the “best transverse profile”, has been located this is used to locate \( e_n \), the road edge in each transverse profile which was used to obtain the “best transverse profile”. To do this each transverse profile used to obtain the “best transverse profile” is compared with the “best transverse profile” to determine the amount by which each individual transverse profile must be shifted to obtain optimum alignment with the “best transverse profile”. This shift is used to calculate the road edge position in each individual transverse profile, \( e_n \).

9.18. This shift is found using cross correlation theory. The approach used is described within these sections (9.18 to 9.28), a sample implementation for this part of the algorithm can be supplied by the SCANNER auditor.
9.19. For any two profiles a correlation curve is defined. This correlation curve is defined formally by calculating at a given lag \( d \) the product of two profiles being compared. The value, \( r \), of the correlation curve for any given lag value, \( d \), is given as:

\[
    r(d) = \sum (\tilde{y}_{i+d} \tilde{y}_i)
\]

where:

- \( \tilde{y} \) is the resampled transverse profiles.
- \( \tilde{y} \) is the “best transverse profile”.
- Index \( i \) varies from 0 to \( N-1 \).
- \( d \) represents the lag value, which indicates the number of re-sampled data points by which the “best transverse profile” must be shifted in order to provide the optimal correlation with any individual resampled transverse profile.

9.20. Note that the above definition for calculating the correlation curve is modified slightly in section 9.23.

9.21. The highest correlation value, \( R \), corresponds to an optimum shift \( d_{\text{max}} \).

9.22. Figure 62 illustrates the principle behind the cleaning algorithm, based on the cross correlation of the best profile with an individual transverse profile. The calculation is iterative. The correlation value \( R \) is calculated for each shift of the best profile with respect to the raw profile. A maximum correlation corresponds to an optimum shift, \( d_{\text{max}} \), for which the optimum alignment of the best profile and the individual transverse profile is obtained.

9.23. The process required to calculate \( d_{\text{max}} \) is described in the following paragraphs.
9.24. The discrete correlation of two real pairs is defined as:

\[ r(d) = \text{corr}(\tilde{y}(i), \bar{y}(i), d) = \frac{\sum_{i=0}^{i=N-d-1} (\tilde{y}(i) - \mu_{\tilde{y}}) (\bar{y}(i + d) - \mu_{\bar{y}})}{(N - d)\sigma_{\tilde{y}}\sigma_{\bar{y}}} \]

with

\[ \mu_{\tilde{y}} = \frac{\sum_{i=0}^{i=N-d} \tilde{y}(i)}{N - d} \]
\[ \mu_{\bar{y}} = \frac{\sum_{i=d}^{i=N-1} \bar{y}(i)}{N - d} \]
\[ \sigma_{\tilde{y}}^2 = \frac{\sum_{i=0}^{i=N-d-1} (\tilde{y}(i) - \mu_{\tilde{y}})^2}{N - d} \]
\[ \sigma_{\bar{y}}^2 = \frac{\sum_{i=d}^{i=N-1} (\bar{y}(i) - \mu_{\bar{y}})^2}{N - d} \]

where:
- \( \tilde{y}(i) \) is the indicial form of the resampled transverse profile.
- \( \bar{y}(i) \) is the indicial form of the “best transverse profile”.
- \( m \) is the index with range 0,1,\ldots,N-1.

9.25. The size of the parameter \( N \) is taken as per the definition in section C.5.

9.26. \( r(d) \), calculated in step 9.24 is the correlation vector of length \( N/2 \). The components of \( r(d) \) are the values of the correlation at different lags with correlations at negative and positive lags stored in a wrap around order. The correlation at zero lag is in \( r_0 \), the correlation at lag 1 is in \( r_1 \), the correlation at lag -1 is in \( r_{N-1} \), the correlation at lag -2 is in \( r_{N-2} \).

9.27. A maximum value of \( r(d) \), \( r_{\text{max}}(d) \) is sought by calculating \( r(d) \) for all \( m < N/2 \).

9.28. \( d_{\text{max}} \) is defined as the lowest value of \( d \) where \( r_{\text{max}}(d) \) occurs, as shown in Figure 62.

**Note:** Sample code is available in C, demonstrating the procedures to be followed in order to calculate \( d_{\text{max}} \).

**Compute the maximum shift and the edge position**

9.29. The following defines the method for locating the edge of the road in each transverse profile:

9.30. The shift value is defined as the lag where the maximum correlation occurs, \( d_{\text{max}} \), as found in 9.28.

9.31. \( d_{\text{max}} \) defines how many resampling steps from the position of the first sensor on the transversal profile have measured features to the left of the road edge (verges, kerbs, etc.).

9.32. \( d_{\text{max}} \), multiplied by the resampling interval, \( t \), defines the edge position along the transversal profile, \( e_n \), where \( n \) indicates the resampled transverse profile being considered.

\[ e_n = d_{\text{max}} \cdot t \]
9.33. Data from measurements made to the left of \( d_{\text{max}} \) are not used in subsequent calculations for assessment of transverse profile described in this document (Sections C.10 and C.11), and are set to 0 (zero).

9.34. The resampled transverse profile, with data from the left of \( d_{\text{max}} \) set to zero is known as the cleaned transverse profile.

C.10 Details of assessment of transverse profile data

10.1. The following definitions are used for the algorithms described herein:
- \( L = \) reporting length: parameterised, recommended value 10m.
- \( \bar{x}_i = \) transverse position of the re-sampled point.
- \( N = \) number of data points in each resampled transverse profile.
- \( t = \) transverse sampling interval in the resampled transverse profile data.

10.2. The algorithms are applied to every individual resampled transverse profile within \( L \), and are concerned only with points to the right of \( e_n \).

**Slope and offset suppression**

10.3. Following the location of the road edge, described in Section C.5, the offset and slope are removed from the individual resampled transverse profiles,

10.4. This is done by finding the best fitting straight line through all valid points in a transverse profile (excluding those which are deemed to originate from the left of the road edge position). This best fitting straight line is then subtracted from the transverse profile data.

10.5. The process is based on a least squares fit and the offset and slope suppression are calculated as follows:

Given the total number of valid data points, \( N' = N - d_{\text{max}} \), in the re-sampled profile, and the resampled profile \( \bar{y}_i \):

\[
\text{slope} = \frac{12 \sum_{i=d_{\text{max}}}^{N-1} i \cdot \bar{y}_i - 6(N'+1) \sum_{i=d_{\text{max}}}^{N-1} \bar{y}_i}{(N')(N'+1)(N'-1)}
\]
\[
\text{offset} = \frac{2 \cdot (2N'+1)(N'+1) \sum_{i=d_{\text{max}}}^{N-1} \bar{y}_i - 6(N'+1) \sum_{i=d_{\text{max}}}^{N-1} i \cdot \bar{y}_i}{(N')(N'+1)(N'-1)}
\]

**Calculation of first derivative of transverse profile**

10.6. The first derivative of the transverse profile data (minus the slope and offset) is calculated. The procedure is as follows:

\[
\hat{y}_i = \frac{\Delta \bar{y}}{\Delta \bar{x}} \Rightarrow \hat{y}_i = \frac{\bar{y}_i - \bar{y}_{i+1}}{t}, \quad i = d_{\text{max}} + 1, \ldots, N - 1
\]
\[
\hat{y}_i = 0 \quad \text{for} \quad i \leq d_{\text{max}}
\]
Calculation of absolute deviation of first derivative

10.7. The absolute deviation of the first derivative of the transverse profile data (minus the slope and offset) should then be found.

10.8. This is defined as:

$$Dev_{FD} = \frac{1}{N - d_{max}} \sum_{i=d_{max}+1}^{N-1} \left( \tilde{y}_i - \frac{1}{N - d_{max}} \sum_{k=d_{max}+1}^{N-1} \tilde{y}_k \right)$$

where $N =$ Number of data points in the resampled profile, $i =$ position index on the transverse profile, $k =$ position index used to calculate average value of first derivative of resampled profile, and $\tilde{y}_i =$ the first derivative calculated at position defined by the index $i$.

10.9. The absolute deviation of the first derivative of the transverse profile data (minus the slope and offset) is calculated for the nearside of the profile as:

$$Dev_{FDNS} = \frac{1}{H - d_{max}} \sum_{i=d_{max}+1}^{H} \left( \tilde{y}_i - \frac{1}{H - d_{max}} \sum_{k=d_{max}+1}^{H} \tilde{y}_k \right)$$

where $H =$ int$\left(\frac{(N-1)+d_{max}}{2}\right)$.

For the offside of the profile, the calculation is:

$$Dev_{FADOS} = \frac{1}{N - H - 1} \sum_{i=H+1}^{N-1} \left( \tilde{y}_i - \frac{1}{N - H - 1} \sum_{k=H+1}^{N-1} \tilde{y}_k \right)$$

C.11 Cleaned rut depth calculations

11.1. $Rut_{NSC}(n)$, the nearside rut depth based on the “cleaned” transverse profile with slope and offset suppression applied (10.3-10.4) should be calculated for each transverse profile within $L$.

11.2. $Rut_{OSC}(n)$, the offside rut depth based on the “cleaned” transverse profile with slope and offset suppression applied (10.3-10.4) should be calculated for each transverse profile within $L$.

11.3. These rut depth calculations should be done following existing methods, compliant with the TTS specification, but instead of using the original transverse profile, data from the resampled and cleaned transverse profiles should be used. This will include only data from the right of the edge position, en.

It is recommended that the rut depth algorithm defined in C.15 is used to calculate the cleaned rut depths. This is based on the TRACS rut depth algorithm. The algorithm should be applied to the Cleaned Profile, with the slope and offset suppression (10.3-10.5) applied, using only the points from position $d_{max}$ to position N-1. This width becomes the full width ‘W’ referred to in the recommended rut depth algorithm the size and boundaries of the quarters used by the TRACS algorithm will vary according to the edge location $d_{max}$.

11.4. The average rut depths in the nearside and offside of the cleaned transverse profiles over the reporting length $L$ are then calculated as follows:

$$Rut_{NSC(ave)} = \frac{1}{T_c} \sum_{n=1}^{T_c} Rut_{NSC}(n) \quad \text{if} \quad T_c > 0$$

$$Rut_{NSC(ave)} = 0 \quad \text{if} \quad T_c = 0$$
11.4.2 \[ \text{Rut}_{\text{OSC(ave)}} = \frac{1}{T_c} \sum_{n=1}^{T_c} \text{Rut}_{\text{OSC}}(n) \quad \text{if} \quad T_c > 0 \]

\[ \text{Rut}_{\text{OSC(ave)}} = 0 \quad \text{if} \quad T_c = 0 \]

Where \( n \) is an index related to the particular transverse profile being considered at any time.

**Note:** This step corresponds to steps C.15.33 and C.15.34 in the recommended rut depth algorithm, C.15. As such, where such an algorithm is used that can report some profiles as invalid for rut depth assessment (such as the recommended algorithm) then the averaging procedure carried out in 11.4.1 and 11.4.2 should be modified to be applied only to the valid profiles, and the value \( T_c \) should be replaced by the number of valid rut depth measurements that have been added up within that 10m length. If the suggested algorithm is used then the minimum number of valid profiles (C.15.34) should be applied, where this condition is not satisfied, then an indication that there is no result should be reported. This may take the form of a numerical code given as the reported value.

**C.12 Reporting**

12.1. \( \text{Dev}_{FD}, \text{Dev}_{FDNS} \) and \( \text{Dev}_{FDOS} \) are calculated for all individual transverse profiles within \( L \). The mean of these \( T_c \) values is then found and defined as \( \text{Dev}_{FD(ave)} \), \( \text{Dev}_{FDNS(ave)} \) and \( \text{Dev}_{FDOS(ave)} \).

12.2. The reported value, \( \text{Dev}_{FD(ave)} \), is the average of \( \text{Dev}_{FD} \) over the reporting length \( L \) defined as:

\[ \text{Dev}_{FD(ave)} = \frac{1}{T_c} \sum_{n=1}^{T_c} (\text{Dev}_{FD})_n \]

where:

\( T_c \) is the number of points over the reporting length defined as: \( T_c = \frac{L}{D} \).

\( n \) is the transverse profile index along the road.

12.3. The reported value, \( \text{Dev}_{FDNS(ave)} \), is the average of \( \text{Dev}_{FDNS} \) over the reporting length \( L \) defined as:

\[ \text{Dev}_{FDNS(ave)} = \frac{1}{T_c} \sum_{n=1}^{T_c} (\text{Dev}_{FDNS})_n \]

where:

\( T_c \) and \( n \) are defined in 12.2.

12.4. The reported value, \( \text{Dev}_{FDOS(ave)} \), is the average of \( \text{Dev}_{FDOS} \) over the reporting length \( L \) defined as:

\[ \text{Dev}_{FDOS(ave)} = \frac{1}{T_c} \sum_{n=1}^{T_c} (\text{Dev}_{FDOS})_n \]

where:

\( T_c \) and \( n \) are defined in 12.2

12.5. The reported value of rutting in the nearside of the cleaned transverse profiles, averaged over reporting length \( L \), is \( \text{Rut}_{NSC(ave)} \).

12.6. The reported value of rutting in the offside of the cleaned transverse profiles, averaged over reporting length \( L \), is \( \text{Rut}_{OSC(ave)} \).
C.13 Solving algebraic equations with a tri-diagonal matrix

A system of equations with a tri-diagonal matrix is written as:
\[ \begin{align*}
    d_1 x_1 + c_1 x_2 &= b_1 \\
    a_2 x_1 + d_2 x_2 + c_2 x_3 &= b_2 \\
    a_3 x_2 + d_3 x_3 + c_3 x_4 &= b_3 \\
    \cdots \\
    a_{n-1} x_{n-3} + d_{n-1} x_{n-2} + c_{n-1} x_{n-1} &= b_{n-1} \\
    a_n x_{n-1} + d_n x_n &= b_n
\end{align*} \]

Set \( d'_1 = d_1 \) and \( b'_1 = b_1 \)

Calculate:

- \( m_i = a_{i+1} / d'_i \)
- \( d'_{i+1} = d_{i+1} - m_i c_i \)
- \( b'_{i+1} = b_{i+1} - m_i b'_i \)

where \( i = 1, 2, 3, \ldots, n-1 \)

Set \( x_n = b'_n / d'_n \)

Calculate: \( x_i = (b'_i - c_i x_{i+1}) / d'_i \), where \( i = n-1, n-2, \ldots, 1 \)
### C.14 Tables for bit reversal

#### Bit reversal for N=2

<table>
<thead>
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<th>Number</th>
<th>binary</th>
<th>Inverse binary</th>
<th>Number of the inverse binary</th>
</tr>
</thead>
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<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

#### Bit reversal for N=4

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<th>Number of the inverse binary</th>
</tr>
</thead>
<tbody>
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<td>00</td>
<td>00</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>01</td>
<td>10</td>
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<td>2</td>
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</tr>
<tr>
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<td>11</td>
<td>11</td>
<td>3</td>
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</table>

#### Bit reversal for N=8

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<th>Inverse binary</th>
<th>Number of the inverse binary</th>
</tr>
</thead>
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<td>2</td>
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</table>
C.15 Rut depth algorithm

This algorithm is recommended for the calculation of cleaned rut depths, it should be applied to the re-sampled and cleaned profile, with points to the left of the located road edge removed.

This algorithm is based upon the TRACS algorithm for the calculation of Rut depth (as defined in ‘TRACS – Services Supply Contract Schedule 2 – The Services and Deliverables’ section E.1.) with a number of modifications.

C.15.1 General Principle

C.15.2 The general principle should be to replicate the use of a 2m straight edge with one end positioned close to the left edge of the lane for the Nearside rut and close to the right edge of the lane for the Offside rut, as shown in Figure 63. Rut depths are measured perpendicular to the straight edge.

C.15.3 However before the Rut Depths can be calculated some basic checks are needed to eliminate invalid sensor measurements and to identify inadequately measured profiles. Invalid measurements may be caused by the sensors overlapping a feature such as a Kerb. Inadequately measured profiles may be caused by there being insufficient sensors outside the wheelpath. The operation of determining each individual Rut Depth can therefore be broken down into three stages:

1. Identify and eliminate any invalid points.
2. Identify an inadequately measured profile (if, within a length over which Rut Depths are to be averaged, more than a pre-defined percentage of individual profiles are “inadequate”, the resulting average Rut Depth should be flagged as “unreliable” within the output).
3. Determine the Rut Depth below an appropriately positioned 2m straight edge.

C.15.4 Calculating individual Rut Depths

C.15.5 The transverse profile is defined as covering a lane of width of $W$ using 20 to 99 points. The points relate to relative distance with each such distance being labelled $D_1$ to $D_n$ in accordance with the corresponding transverse profile point, where $D_1$ is the left-most point and $D_n$ is the right-most point, in the direction of travel. (See Figure 64.)
C.15.6 The lane width is subdivided into four parts, Q₁ being that from the left-most edge to a system or user-defined percentage q (typically 25%) of distance W from the left most edge. Q₄ is that from the right most edge to q% of W from the right most edge. Q₂ and Q₃ equally subdivide the remaining width between Q₁ and Q₄.

C.15.7 Points are reported vertically relative to an artificial ‘horizontal’ datum, with increasing value being upward.

C.15.8 For the purposes of analysis, points that fall exactly on the boundary between Q₁ and Q₂ are deemed to lie within Q₁. Points that fall exactly on the boundary between Q₃ and Q₄ are deemed to lie within Q₄. (Sensor measurements within Q₂ and Q₃ are always considered together.)

C.15.9 **Elimination of invalid points**

C.15.10 Invalid points may be caused by measurements overlapping a Kerb or footway, as shown in Figure 65, where d is a system or user defined parameter (typically 20mm).

C.15.11 In the situation shown in Figure 65, points D₁ and D₂ should be eliminated, i.e. excluded from the calculation of the Nearside Rut Depth.

C.15.12 In the general case, when calculating the Nearside Rut Depth, all points from D₁ to Dₙ₋₁ should be eliminated where (Dₙ₋₁ - Dₙ) > d and Dₙ is within Q₁. Similarly when calculating the Offside Rut Depth, all points from Dₙ to Dₙ₊₁ should be eliminated where (Dₙ₊₁ - Dₙ) > d and Dₙ is within Q₄.
C.15.13 **Identification of an inadequately measured profile**

C.15.14 An inadequately measured profile may be caused by there being insufficient points outside the Wheelpath, as shown in Figure 66, where s is a system or user defined parameter (typically 2%). If, within a length over which Rut Depths are to be averaged, more than a system or user-defined percentage P (typically 25%) of individual profiles are “inadequate”, the resulting average Rut Depth should be flagged as “unreliable” within the output.

C.15.15 In the situation shown in Figure 66, the profile should be considered as “inadequate”, and the Nearside Rut Depth should not be calculated.

![Figure 66](image)

C.15.16 In the general case, when calculating the Nearside Rut Depth, if the slope from $D_1$ to $D_{1+\lambda}$ exceeds s% (downwards) the profile should be considered “inadequate” and the individual Rut Depth should not be calculated. Similarly when calculating the Offside Rut Depth, if the slope from $D_z$ to $D_{(z-\lambda)}$ exceeds s% (downwards) the profile should be considered “inadequate” and the individual Rut Depth should not be calculated. If, when calculating an average Rut Depth, more than P% of the individual profiles were “inadequate”, the resulting average Rut Depth should be flagged as “unreliable” within the output.

The value for $\lambda$ should obtained by dividing 100mm by the transverse spacing of the re-sampled profile points. For a 25mm re-sampled profile point spacing, this gives $\lambda = 4$.

C.15.17 N.B: When calculating the Nearside Rut Depth, if point $D_1$ has been eliminated as defined in Section C.15.10, the check for an inadequately measured profile should not be carried out. Similarly, when calculating the Offside Rut Depth, if point $D_z$ has been eliminated as defined in Section C.15.10, the check for an inadequately measured profile should not be carried out. In such cases the measured profiles should always be considered as adequate.

C.15.18 **Calculation of Nearside Rut Depth**

C.15.19 Having eliminated any invalid points (as described in Section C.15.10) and assuming that the profile is not considered “inadequate” (as described in Section C.15.14) the Nearside Rut Depth should be calculated as follows:

C.15.20 **Position of notional straight edge**

C.15.21 N.B. Within the following paragraph, distance L is the length of a notional straight edge (typically 2m). This length and minimum distance $l$ (typically 0.6m) must be configurable within the applications software.

C.15.22 For each point $D_n$ ($n = 1, 2, 3$ etc., but excluding invalid points) within $Q_1$, it shall be ascertained whether there is a corresponding point $D_a$ which is to the right of, within distance L of, and at least distance $l$ from point $D_n$, and (b) such that all points to the right of and within distance L of point $D_n$ lie on or below a line of length L drawn from point $D_a$ and...
passing thought point D_p. Once a pair of points D_n and D_p has been found that satisfies the conditions, the searching process shall stop (Figure 67).

C.15.23 Figure 67 (upper) demonstrates that there is no point corresponding to point D_1 that satisfies the stated criteria (points D_2 and D_3 lie above all lines from point D_1). Similarly, there is no point corresponding to point D_2 that satisfies the stated criteria (point D_3 lies above all lines from point D_2).

Figure 67

C.15.24 Figure 67 (lower) shows that there is a point (D_{12}) corresponding to point D_3 that satisfies the stated criteria (all points from D_4 to D_{16} inclusive lie either on or below the line of length L from point D_1 passing through point D_{12}). This therefore represents the correct position for the notional straight edge.

C.15.25 If no pair of points can be found that satisfies the stated criteria, the Nearside Rut Depth shall be set to zero.

Figure 68
C.15.26 **Calculation of depth and offset to each intervening point**

C.15.27 The depth (d) and offset (l) of each point lying between D_n and D_p, relative to the notional straight edge, to can be calculated as follows:

\[(x_n,y_n) = \text{Offset and height (within transverse profile) of point } D_n\]
\[(x_p,y_p) = \text{Offset and height (within transverse profile) of point } D_p\]
\[(x_a,y_a) = \text{Offset and height (within transverse profile) of point } D_a\]
\[(x_a,y'_a) = \text{Offset and height (within transverse profile) of the point on the notional straight edge vertically above point } D_a\]

\[S = \sqrt{(y_p - y_n)^2 + (x_p - x_n)^2}\]
\[h_a = \sqrt{(y_a - y_n)^2 + (x_a - x_n)^2}\]
\[d_a = \frac{(x_p - x_n)(y'_a - y_a)}{S}\]
\[y'_a = y_n + \frac{(x_a - x_n)(y_p - y_n)}{(x_p - x_n)}\]
\[l_a = \sqrt{h_a^2 - d_a^2}\]

C.15.28 **Calculation of Rut Depth**

C.15.29 The Rut Depth is calculated as the maximum value of d.

C.15.30 **Calculation of Offside Rut Depth**

C.15.31 Offside Rut Depth shall be calculated in the same way as, but a mirror image of, the Nearside Rut Depth, i.e. working from the right edge of the transverse profile.

C.15.32 **Average Rut Depths**

C.15.33 For each Wheelpath, the average Rut Depth over the prescribed length (e.g. 10m) shall be calculated by averaging the individual Rut Depths for that Wheelpath, including zero Rut Depths but excluding inadequate transverse profiles.

C.15.34 If more than a system or user defined parameter (typically 25%) of the individual profiles were “inadequate”; the resulting average Rut Depth should be flagged as “unreliable” within the output.
Appendix D. Enhanced Techniques

The data collection and processing steps for the enhanced methods for identifying edge deterioration described in this appendix are a summary description of the equipment and algorithms required for the enhanced detection to edge deterioration.

D.1 Data Collection

The data collection equipment requirements are as follows:

Profile system:
- Transverse profile measurement extending at least 1m past the nearside of the survey vehicle.
  - Measurement should span the width of any images collected.
- Profile data reported at transverse spacings of 10mm or less. However it is considered likely that a transverse spacing up to 25mm will retain most of the performance.
- Profile data should be reported at longitudinal spacings of 100mm or less.
- Profile measurement accuracy requirements should be similar to the requirements for the current SCANNER and TRACS surveys.
- Profile height measurement range to span from the top of kerbs to the bottom of potholes and verge rut features – we would suggest, from our experience, a minimum vertical range of 200mm, in addition to changes in height relating to vehicle ride height.

Image System:
- Colour downward facing images over a width extending from the offside to at least 1m to the left of the survey vehicle nearside.
- The images require a resolution giving a pixel size of approximately 6mm for the image processing algorithms described herein.
  - This may be achieved by post-processing images collected at a higher resolution.
- Contrasts caused by sunlight and shadow should be minimised within each collected image. We suggest that this is achieved through the use of high power lighting in conjunction with the image collection system.

Survey Vehicle:
- The data collection systems must be fully integrated such that the image and profile data is transversely and longitudinally aligned to an accuracy of a few mm.
- It is preferable that the data can be collected at traffic-speed.
- The system should be able to collect image and profile data over the verge without physical obstruction through collision of the vehicle or attached equipment with the verge, walls, furniture or vegetation.
- The vehicle should be compact and manoeuvrable enough to enable surveys of B, C and U class narrow rural and urban roads at traffic speed.

D.2 Processing Algorithms

D.2.1 Location of the road edge

Firstly, the edge of the road and verge is located using image processing. The method is a further development of the work carried out by the Transport Research Foundation (Watson & Wright, 2006). A summary of this procedure follows:
- The Hue, Saturation and Intensity (HSI) image is calculated from the original image.
The average hue and saturation value for the road surface part of the image is calculated from a region defined on the right side of the image, within the vehicle wheeltrack.

The standard deviation of the hue and saturation in this same region is calculated.

- The calculation of the standard deviation of Hue has been modified from the equation given in Watson & Wright 2006, to incorporate the cyclic nature of the Hue value.

A new image is calculated by giving two values to each pixel that reflect the difference of the pixels hue and saturation values from the relevant sampled mean values. These differences are normalised according to the standard deviation calculated for each and scaled to produce a ‘closeness’ image that can be viewed.

- The scaling used to produce the image has been further optimised since Watson & Wright 2006.

A procedure (Watson & Wright, 2006) is applied to segment the image into smaller areas by making use of the closeness image values. This results in a number of smaller segments typically concentrated around the road edge region of the image.

- Some specifics of this segmentation have been further developed for this project.

The road and verge edge lines are determined by selecting the appropriate segment boundaries according to an iterative process which locates the boundaries of segments that satisfy certain pre-defined criteria.

- The criteria used herein have been further developed from those employed in previous work.

The images used within this work each cover 2m in the longitudinal direction. The road and verge edge is found for each consecutive road edge image. The road and verge edge lines produced, defined by a lateral location being reported every 100mm along the survey.

### D.2.2 Location of road and kerb step edge

A step edge can be found in the transverse profile data where the road edge features an upward step (i.e. a kerb or bank) or a downwards step (i.e. a rutted verge). Additionally, a downward step edge may be found in the transverse profile data where a pothole or a severe deformation of the road surface occurs.

The transverse profile data is processed to identify the location and step height of the first step (upwards or downwards) above a predefined step size, reached when moving along the profile from the centre line of the vehicle to the nearside. This is the profile step edge. Starting from this position, the algorithm continues along the profile looking for only an upward step, greater than a second threshold. If a second step is identified this is labelled as the profile kerb step location. The method used herein has been a development of that described in Watson & Wright 2006.

### D.2.3 Further image and profile data processing

Additional processing is carried out by cross referencing the image and profile data. A combined road edge is defined. This is evaluated at each chainage position along the survey as described in Watson & Wright 2006. This combined edge follows the image road edge apart from where the profile step edge is found further to the offside, such as at defects such as potholes. As such it can be seen as a boundary that segments the intact road surface from the verge, or deteriorated road surface.

The profile step edge locator only reports steps where they occur above a certain threshold. This means that there will be gaps in the measurement of the road edge step. To obtain a continuous measurement of edge step height an ‘image located step’ is calculated by examining the profile data across the location corresponding to where the road edge has been found by image processing. It may be that this part of the profile does not contain a significant step edge, in which case a low value will be given.

The method proposed for the detection of raised kerbs at the road edge makes use of an additional measurement from the image. At the location where an upward step edge is found in the profile data,
an ‘intensity step’ is calculated from the image intensity values corresponding to where the profile step has been calculated. In many cases, a measurable intensity step increases confidence that the upward profile step is a kerbstone.

Additionally the image data is analysed to determine whether the image is fully surfaced. Typically the image segments produced for the evaluation of the road edge (D.2.1) result in a larger segment to the left of the image containing the verge. The hue and saturation ‘closeness’ values for this segment are extracted.

**D.3 Interpretation of data**

From the processing algorithms, we extract intermediate information from the image and profile data. These are listed below. This information is delivered at a regular longitudinal interval of 100mm.

- Road edge location - lateral position.
- Verge edge location - lateral position.
- Profile step edge location and heights - lateral position and height.
- Profile kerb step location and heights - lateral position and height.
- Combined edge location - lateral position.
- Image located step edge - height.
- Image intensity change across profile kerb step location - intensity step value.

Additional information is extracted with a value given for each edge image (every 2m of the survey):

- Hue and saturation ‘closeness’ values for the image segment containing a particular co-ordinate on the left side of the image.

**D.3.1 Determining defects**

This derived data enables us to identify defects associated with edge deterioration. This project has further developed the ideas presented in the TRF research (Watson & Wright, 2006) for the calculation and reporting of parameters over a reporting interval (typically 10m). These methods are described in this report (sections 8.5 and 8.6) and are summarised here.

**Overriding**

The lateral gap between the image derived road and verge edge is established at each 100mm, this indicates the width of overriding. The percentage of the reporting length for which this width exceeds a particular threshold is calculated.

**Rutting of the verge**

The overriding width is calculated as above. Rutting of the verge is indicated at locations where the width threshold for overriding is exceeded and the profile step edge indicates a downward step exceeding a particular threshold.

**Edge Stepping**

The image located step height is examined and the proportion of each reporting length is reported where this height falls within the interval 20mm to 50mm downwards, and also where the height is greater than 50mm downwards.

**Potholes and surface deformation**

The combined road edge and the road edge identified in the image are compared. At each 100mm point we evaluate the gap between the combined and image road edges. The proportion of each reporting length where this gap exceeds a particular threshold is reported.
**Raised kerb**

The image located road edge and profile located kerb step position are compared every 100mm. The proportion of the length satisfying the conditions below is reported as an indicator of raised kerbs.

- The kerb edge position is to the right of or equal to the image road edge position and is inside of the left edge of the image.
- The kerb step height is greater than 100mm.
- The image intensity step is greater than +25, with the higher intensity found on the left.

**Surfaced verge**

Where the hue and saturation closeness values obtained from the left hand region of the image both exceed a particular threshold, it is determined that the left side of the image is surfaced. The proportion of images where this is the case is reported for each reporting length.

**D.3.2  An enhanced indicator for edge deterioration**

The defects described in D.3.1 may be combined using a similar method as developed for the initial SCANNER methods (section 7) – a weighted average of the normalised parameters. In this report we have looked at a weighted average of some of the enhanced parameters specifically for the purpose of comparison with the initial indicator. An enhanced indicator may be developed further through the addition of further parameters, carrying out normalisation with a representative dataset and fine tuning the weightings used.
Appendix E. Specification for combined Edge Deterioration Indicator

The Edge Deterioration Indicator is calculated from the following Initial Parameters which are reported for each ten metre reporting length:

- LEDR: Edge Roughness
- LTRV: Transverse Variance Difference
- LES1: Edge Step level 1
- LES2: Edge Step level 2

To calculate the Edge Deterioration Indicator value, each parameter is normalised between two thresholds using the following procedure, where x is the original parameter and y is the normalised parameter value:

- If \( x \geq T_{upper} \), \( y = 1 \).
- If \( x \leq T_{lower} \), \( y = 0 \).
- If \( T_{lower} < x < T_{upper} \), \( y = \frac{x - T_{lower}}{T_{upper} - T_{lower}} \).

The values for \( T_{upper} \) and \( T_{lower} \) are specific to each parameter, the values are listed in Table 14. Note that for LES2, both thresholds are zero. This means that any non-zero value for the parameter LES2 is normalised to 1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>( T_{upper} )</th>
<th>( T_{lower} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEDR</td>
<td>0.160858</td>
<td>0.035443</td>
</tr>
<tr>
<td>LTRV</td>
<td>71.08441</td>
<td>7.235398</td>
</tr>
<tr>
<td>LES1</td>
<td>5.000001</td>
<td>0</td>
</tr>
<tr>
<td>LES2</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 14: Thresholds for calculating normalised parameter values.

The value of the combined Edge Deterioration Indicator is calculated from the normalised parameters as follows:

\[
\text{Edge Deterioration Indicator} = W_r y_{LEDR} + W_{tv} y_{LTRV} + W_{E1} y_{LES1} + W_{E2} y_{LES2}
\]

Using the weighting values below:

- \( W_r = 30 \)
- \( W_{tv} = 15 \)
- \( W_{E1} = 25 \)
- \( W_{E2} = 30 \)

The resulting Edge Condition Indicator takes a value in the range 0-100.

The Edge Deterioration Indicator should then be aggregated and reported over 100m lengths. This should be achieved by calculating the mean average of the indicator values calculated as above, over consecutive 100m sections of a survey.

An Edge Condition Indicator value, \( ECI \), can be categorised into three levels by the application two thresholds \( ECI_{l1} \) and \( ECI_{l2} \) as follows:

- Level 0 edge condition: \( ECI < ECI_{l1} \)
- Level 1 edge condition: \( ECI_{l1} \leq ECI < ECI_{l2} \)
- Level 2 edge condition: \( ECI \geq ECI_{l2} \)

For the 100m reporting interval recommended, the threshold values applied should be \( ECI_{l1} = 10 \) and \( ECI_{l2} = 30 \).