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PUBLISHED PROJECT REPORT PPR001

TTS Initial Review – Review of Survey Methods

Version: 1.0

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Prepared for: Project Record:	**Review of Current Automated Road Condition Surveys**
Client:	**Edward Bunting, Traffic Management Division, Department for Transport**

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Executive summary

Project Title: **TTS Initial Review - Review of Survey Methods**

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Objectives of Project

The objective of this project is to review the lessons learned from automated road condition surveys carried out to date on UK road networks and identify the requirements for the new automated road condition surveys on all local roads to be introduced in 2005.

- The review aims to identify the current use of automated road condition surveys in Europe and the rest of the world from experience, literature searches and electronic communication, and hence highlight where the UK could usefully learn from experience outside the UK.
- The review also aims to carry out a brief consultation exercise with a limited number of key experts in the field of local road maintenance and road surveying techniques, to confirm the initial requirements from TTS.

Project Outputs

The project was required to provide detailed feedback from the consultation exercise both in writing and via verbal presentation to key stakeholders

The project was also required to provide feedback on the assessment of measurements made using current survey techniques (TTS and manual) in order to assess the:

- Use of these types of measurement in measuring the condition of the main types and classes of local roads.
- Use of these types of measurement in identifying the maintenance need of the main types and classes of local roads.
- Effect of different analysis techniques on the same TTS measurements.
- Potential for modifying current measurement techniques to suit the requirements of all types and classes of local roads.
- Requirements for measurement and analysis of defects not currently covered by existing automated road condition surveys.
- Requirements for measurement and analysis of pavement types not currently covered by existing automated road condition surveys.
- Potential for improvements in maintenance management using TTS measurements with different or changed business processes.

The requirement for the final output of the project was a brief but comprehensive report covering all aspects of the review and specifically identifying the requirements for the introduction of the new surveys on non-principal roads in 2005/06 and on all local roads in 2007/08.

TRACS Type Surveys (TTS) have been introduced by the DfT on the Principal Road Network (PRN) in April 2004, and are to be introduced on the non-Principal Road Network (non-PRN) in April 2005.

These TTS surveys are to replace the current regime of visual inspections for routine condition monitoring and generation of the Best Value Performance Indicator (BVPI). Research in this area to date has concentrated on the successful implementation of the technology to the trunk road network. It was recognised in the TRACS Type Surveys for Local Roads Scoping Study that the conditions encountered on the non-PRN may differ from those of the larger and better constructed trunk roads.

It was therefore recommended in the Scoping Study that an initial review be carried out to determine the capabilities of existing TTS regimes, and how these may be adapted for use on the non-PRN. The review should also address any shortcomings of the existing TTS where they were unable to provide the data required for successful management of the non-PRN maintenance programmes.

This review drew on experience and research in the field of automated traffic speed pavement condition monitoring from both the UK and overseas, consulted with key experts in local road maintenance and monitoring to confirm the initial requirements of TTS on local roads, and involved a short data analysis exercise comparing the results of TTS and visual surveys which were carried out on selected roads.

No evidence was found that the use of automated condition surveys on local roads had been researched extensively abroad. The consultation with UK based experts found no entrenched opposition to the principle of TTS, but there were strongly held concerns regarding the current capabilities of the technology and the proposed timescale for introduction on the non-PRN.

It was determined that in order for TTS to be acceptable to local maintenance engineers the surveys must be able to identify rutting, cracking, surface and edge deterioration as a minimum.

The detection of edge deterioration is not currently performed in TTS surveys, and is something which will require research prior to the introduction of the surveys. It was established that the simple detection of edge deterioration, without any additional details regarding the nature or severity of the deterioration may be an acceptable first step.

The data analysis exercise has shown that the presence of edge deterioration cannot be simply derived from TTS measurements such as cracking, rutting or profile variance, as no strong correlations were observed between these parameters and the visually observed edge deterioration.

Analysis of the data has shown that the TTS detection of cracking is consistently lower than the visual. Assuming the visual measure of cracking is reasonable (for which only an assumption can be made given the current data) this highlights a need for improvements to the crack measurement. However, care would need to be taken in this area to ensure that the reasonably low false positive nature of the TTS is maintained.

The data comparison has shown that there are distinct differences in the level of accuracy and sensitivity of visual and TTS rut measurements, with the visual surveys displaying less sensitivity to small changes in the severity of defects, and tending to assess pavement subsections as being more defective than the TTS surveys.

Several areas of TTS have been noted where further research would enhance the survey performance on the non-PRN. These include the reliable detection of edge deterioration; improvements to the crack detection system; the development of methods for utilising data on longitudinal unevenness; the ability to detect ‘other visual defects’ such as fretting or polishing; and the use of TTS measured texture information as a proxy measurement of skid resistance.

The review also concluded that there are currently insufficient accredited survey vehicles available for performing routine network wide surveys of the non-PRN, and raised the idea of introducing an accreditation procedure for vehicle operators and drivers in addition to the accreditation procedures applied to the vehicles.

1 Introduction

The DfT intends to introduce TRACS Type Surveys (TTS) on the Principal Road Network (PRN) and the non-Principal Road Network (non-PRN). The first stage of these surveys, which will be carried out on the PRN, began in April 2004. These will be followed by the expansion of the TTS to include the non-PRN in April 2005.

The TTS surveys are to be used to replace the current regime of CVI and DVI surveys for routine condition monitoring and generation of the Best Value Performance Indicator (BVPI). However, while TRACS surveys have been implemented successfully on the trunk road network, it was recognised in the TRACS Type Surveys for Local Roads Scoping Study (Ekins and Hawker, 2003), that the needs of the non-PRN may differ from those of the larger and better constructed trunk roads. Therefore the exact nature of the data required from surveys of the non-PRN is, as yet, undefined.

The Scoping Study therefore recommended that initial research be carried out into existing survey regimes in order to ascertain the requirements for these new TTS on non-PRN, and to review the lessons learnt from surveys undertaken thus far. This review would:

- draw on experience and relevant developments or research carried out overseas
- draw on the experience gained in carrying out traffic speed condition surveys on UK roads
- consult with key experts in the UK in the field of local road maintenance and road surveying to confirm the initial requirements for TTS on non-PRN.

The results of this review are presented in this report.

The results of the consultation exercise were also presented to other parties involved in the initial research projects at a TRL presentation. The PowerPoint presentation slides which were used to deliver this feedback are included as Appendix C.

2 Method of Approach

The review was carried out in three phases:

<u>Phase 1</u>

Phase 1 was a consultation and review exercise, and was itself split into two sub-phases. The first part of Phase 1 was a consultation exercise with overseas experts; the second part involved consulting UK based experts.

The overseas consultation exercise was designed to provide a summary review of existing overseas experience and developments. This was done in order to ensure the DfT would share in any lessons learnt or research carried out elsewhere in the world.

The UK expert review involved consulting local authority engineers with and without existing experience of TTS or other machine based surveys. This stage also involved contacting survey providers and equipment developers and manufacturers.

The feedback given during earlier workshops and seminars which had been held by the DfT to discuss the implementation of TTS on local roads was also utilised in Phase 1 of the review.

<u>Phase 2</u>

Phase 2 took the form of a short data analysis exercise in which the usefulness and appropriateness of TTS survey data was assessed against data collected during Coarse Visual Inspections (CVI data). This data analysis was performed in two ways; firstly a ‘network wide’ assessment was carried out in which the lengths of road said to be affected by various key defects were compared, and secondly a selection of sites which had been flagged by the visual inspection as having interesting defects were investigated in detail to determine how the machine based surveys had assessed the pavement.

<u>Phase 3</u>

The third and final phase of the review was the reporting of the findings of the consultation exercise and the data analysis. This third phase culminates in this report.

3 Previous Consultation

During the autumn of 2003 a series of seminars and workshops was held (at TRL in Crowthorne, in Stockport and in Cheltenham) at which the proposals for the implementation of TTS on local roads were explained and discussed. These gave local authorities the chance to make their feelings known and to be involved in the process. Among the many issues raised, the following key points were discussed:

- It was felt that TTS would provide objective and impartial data which would aid in funding applications
- The current inability of TTS to detect edge deterioration was a major shortcoming of the system
- There was a desire to distinguish between surface and structural rutting
- To be successful TTS must be able to be performed on a 'full' range of local road surface types
- TTS should ideally be able to distinguish between the many types of cracking
- The number of survey vehicles currently able to perform TTS is not large enough
- The fact that TTS cannot replicate the information gathered during a CVI was of concern to some
- People's confidence in TTS must be raised – it was felt that they wished to use TTS data, but were not yet convinced it would give them what they needed.

These feelings and answers were borne in mind and helped to provide a focus and direction for the questions asked in the consultation exercises.

4 Overseas review and experiences

After consideration of current knowledge, and the concerns and questions already raised in the previous UK consultations, a list of questions was drawn up and sent to selected overseas experts involved in the field of machine-based pavement condition monitoring. These questions were designed to ascertain the depth and scope of experience in the subject which was held overseas. The experts selected included governmental research organisations, as well as private companies, survey providers and equipment suppliers. The questions are summarised in Appendix A.

Respondents were asked for their feelings and experiences on a wide range of subjects, and were encouraged to give as much or as little detail in their answers as they saw fit.

4.1 Summary of responses

A total of 11 responses were obtained from the overseas experts. These included practitioners from Europe, North America and Australasia. The survey was also sent to experts in several other countries, including France, Germany, Spain, Italy and Portugal, but unfortunately no responses were forthcoming from these countries for inclusion in this report. The list of respondents is given in Table 1.

Name	Organisation	Country
Trenton Clark	Virginia Dept of Transport	USA
Max Grogg	US-FHWA	USA
Mathieu Grondin	Government of Quebec	Canada
Barry Jan	ARRB	Australia
Tom Jermyn	NRA	Eire
Bryan Pidwerbesky	Fulton Hogan	New Zealand
David Pratt	CSIRO	Australia
Leif Sjögren	VTI	Sweden
Harri Spoof	VTT	Finland
Jean Claude Turtschy	LAVOC-EPFL	Switzerland
Max Von Drehnen	Transit National Office	New Zealand

Table 1: List of respondents in overseas expert consultation

4.2 Key findings

The following is a summary of some of the key results of the overseas consultation, concentrating on the most frequent responses, or those directly relevant to the task of introducing TTS on UK local roads.

4.2.1 Measured Parameters

When asked which measurements were currently being routinely carried out on their networks:

- Longitudinal profile, transverse profile/rutting were measured by all respondents
- Texture or surface friction proxy measurements were carried out by most respondents
- Cracking was not measured routinely; of those who responded only the Australians had the capability to perform crack measurements routinely
- Several of the respondents expressed a desire, or said they had been working on developing techniques, to reliably detect and measure cracking

Further information on the measurement of cracking in particular was provided by a number of the respondents. The respondents from Australia provided further information regarding their crack measurement equipment (Ferguson and Pratt). This equipment, the RoadCrack system, detects cracking using an image based system, which identifies cracking and subsequently expresses the severity of the cracking in terms of crack width. However, Offrell and Sjögren (Swedish respondents) also provided further information regarding the measurement of cracking and in particular discussed the appropriateness of various crack measures and methods of expressing crack severity. This work concluded that crack width should not be recommended as a measurement of crack severity. It is apparent that such work highlights the problems and disagreements which are still encountered in the automatic detection and measurement of cracks.

4.2.2 Key Concern Area – Edges

As stated in Section 3, edge deterioration is a recognised area of concern for which TTS is not currently able to provide detailed information. The overseas consultation also reviewed this subject, with the following key responses.

- Edge deterioration is not considered an area of concern for many respondents as their surveys tended to be carried out only on their equivalents of the UK Motorway and trunk road network.
- Several respondents did express that the detection of edge deterioration was of interest on their networks, but this deterioration was not a priority
- Only one respondent (Leif Sjögren, VTI, Sweden) had carried out research and development in this area, and reported the existence of an algorithm which combined the outputs from existing sensors to try and flag the presence of edge deterioration. Details of this algorithm have not been published, but correspondence has indicated that the deterioration is assessed on the basis of the recorded transverse profile and crossfall of the pavement.

4.2.3 Data Quality Issues

A number of the responses could be brought together under the general title of data quality, as they related to problems including data accuracy, location referencing and survey procedures. The key responses in this area are summarised in this section.

- The need for control and consistency was stressed - those respondents who had experience of switching from using one type of automated system to another tended to experience problems related to the system change. Similar problems were experienced by the UK Highways Agency when moving from HRM to TRACS surveys. In anticipation of this change, and even though both systems were of comparable accuracy, a network wide assessment was carried out to determine the extent of the effect of this change on the calculated condition indicators and the use of the survey data.
- It was stated that the quality of data gathered was often very dependent on the driving line of the survey vehicle, this was especially true when dealing with rut measurements
- It was indicated by one respondent that by carrying out quality assurance checks on rut measurements during the survey the quality of the results and the efficiency of the surveys could be improved

  The idea of the survey operator performing a QA function on the data as it was collected, and determining whether or not a repeat survey was required is interesting as this idea was echoed in the UK consultation with the suggestion of both driver and operator accreditation (discussed in Section 5.2.2).
- Most respondents who gave any details of their transverse profile systems had automatic algorithms which would discard transverse profile points believed to have been gathered over kerbs. This is also the case in the UK and almost all equipment manufacturers/operators use such a system to improve the accuracy of their rut measurements. No detailed data was provided showing how efficient these methods were at solving problems associated with kerbs and other edge features.

4.2.4 Other Issues

It is noted that some of the respondents had significantly different road networks and climates to those in the UK, and they may therefore also have different concerns, issues and priorities. However, other issues raised included:

- One respondent was undertaking research on the use of a scanning laser for transverse profile measurements (Max Grogg)
- One respondent is investigating road sign recognition and road line monitoring technologies (Mathieu Grondin).

It is noted that methods for the measurement of road line condition using automatic techniques is a current topic of research in the UK. The Highways Agency is funding research into the suitability of various systems for the measurement of retro-reflectivity on the UK trunk road network. Furthermore, the use of scanning laser techniques for enhanced transverse profile measurements is also being investigated by the Highways Agency.

4.3 Overseas expert consultation – Summary

- No evidence was found that defects other than those which are used in the UK are routinely detected
- Experience abroad is largely limited to trunk road equivalents
- Very little research has been done on the application of automated machine based condition surveys to local monitoring
- The Swedes have developed a basic edge deterioration algorithm based on information contained within the transverse profile.

5 UK review and experiences

A separate list of questions was drawn up and sent to selected UK experts involved in the field of machine based pavement condition monitoring. These questions are included at the end of this report as Appendix B.

Respondents were asked for their feelings and experiences on a wide range of subjects, and were encouraged to give as much or as little detail in their answers as they saw fit. This initial contact and questionnaire was often followed up with telephone interviews to those experts who highlighted any really interesting points, and also to elicit response from some of those who did not respond to the email.

5.1 Summary of responses

A total of 13 responses was obtained from the UK experts, as summarised in Table 2.

Name	Organisation
John Ekins	Ex Hampshire CC
Simon Mitchell	Bracknell Forest
Ian Brownell	RB Windsor & Maidenhead
Garry Warner	Bexley
Gordon Prangnell	Hammersmith & Fulham
John Thorp	Lancashire
Peter Burnham	Worcestershire
Alistair Gow	SRMCS
Gary Fitch	Kent
Peter Naile	Devon
David Arran	Scotland
Jimmy McCullough	Northern Ireland
Robert Epps	Cornwall

Table 2: List of respondents in UK expert consultation

5.2 Key findings

The following summarises the key results of the UK consultation, concentrating on those responses which were most frequently given, or which are directly relevant to the task of introducing TTS on local roads by April 2005.

5.2.1 Experience and Attitudes

Almost all of the survey respondents had at least some experience with TTS, or some other form of automated pavement condition monitoring survey. Their responses were therefore derived from experience in the use of the technology and an awareness of its capabilities. It was clear from the responses, and also from correspondence and discussion, that even those without direct experience of using TTS were well informed and were aware of the capabilities and weaknesses of current TTS technology.

- None of the experts consulted had any objections to the idea of TTS, although some did express doubts over its suitability in its current state
- As in the previous workshops (Section 3), it was felt that the objectiveness and consistency would be a major advantage for TTS
- Respondents were satisfied that TTS would prove useful, given time to allow meaningful trend data to be collected
- Several respondents stated that they prefer to establish one survey method and not have to change every few years

The key findings in this area were that while none of the respondents had any objections to the principle of TTS, and were therefore approaching the subject with suitably open minds, several had reservations, ranging from minor to serious, about the capability of TTS to provide them with the necessary data at this point in time.

The idea of introducing TTS now, and allowing it to develop over the next few years without necessarily having fixed deadlines and timescales for what it will and will not be able to do was also suggested by some respondents.

*5.2.2 **Doubts / Concerns***

The respondents were asked to express their doubts and concerns concerning the replacement of CVI survey data with that collected using TTS methods and equipment. The key concerns were:

- TTS cannot detect edge deterioration, and is unlikely to do so reliably by 2005
- Crack detection was described as being a “hit and miss affair”, which it was felt must be improved
- CVI can distinguish between different types of cracking (wheeltrack, transverse/reflective, or whole carriageway), whereas TTS cannot, as yet, do this
- If TTS is adopted then separate footway inspections will need to be carried out, which will add to the cost of the survey process
- TTS is perceived as being poor at detecting ironwork defects
- Traffic calming measures, particularly on urban roads may make passage of TTS vehicle impractical
- The whole concept of TTS on urban estate roads was questioned by several respondents
- The number of TTS vehicles in the country was considered insufficient to enable the successful introduction of mandatory TTS surveys
- TTS does not currently require formal machine operator or driver accreditation. It was felt that this may lead to poor data quality

The key doubt held by respondents regarding the introduction of TTS in 2005 was its current inability to detect and describe edge deterioration. This is seen as a very important defect, and the fact that TTS cannot detect it at the moment is a major obstacle to its acceptance as a survey method. However, the concerns over the detection of edge deterioration were stronger within rural authorities than they were for urban authorities. This is largely because a higher proportion of the roads contained within urban areas are designed roads (incorporating design and engineering in their construction), and these roads typically have supported (kerbed) edges. In contrast, many of the more rural roads have evolved over time, have no kerbing or edge support, and are hence more vulnerable to water ingress and overriding.

Of only slightly less concern was the reliability of the crack detection system, and the fact that at present this is unable to distinguish between the various types of cracking.

The expression of doubt regarding the practical issues of insufficient vehicles, and the daily mileage being prohibitively low in urban residential areas are concerns that have been expressed previously. Such concerns must be taken into account when drawing up firm implementation plans for TTS.

The idea of having operator or driver accreditation stems from the fact that significant effort and resource is allocated to ensuring that the TTS vehicles and instrument systems are correctly calibrated and have satisfactory levels of accuracy. However, no qualifications are needed for the human component of the system. It was felt by some that this seems anomalous given that human error or incorrect operation could result in totally meaningless results no matter how accurate and reliable the TTS system is.

It seems reasonable to include the need for regular, independent accreditation and quality assurance procedures to be included in any specifications for the implementation of TTS.

5.2.3 ***Visual Surveys***

The experts were asked to provide their opinions on how useful they found the parameters reported in manual (CVI) surveys. Their responses allowed the separation of CVI defects into those which are essential to detect if present, and those which are desirable to know about.

5.2.3.1 Defects which are essential to detect

The following defects were considered the most important defects reported in existing CVI surveys, and as such were deemed essential in any TTS system:

- Rutting
- Cracking
- Edge deterioration
- Surface deterioration

It is interesting to note that Appendix 11 of the UKPMS Visual Survey manual states that the…

> *"recommended approach to the collection of wheel track rutting is to use a machine-based technique. … either laser or ultrasonic techniques are acceptable for the purpose of measuring rut depth, providing the equipment can be shown to be calibrated to ±2mm accuracy"*

Machine measured rut depth values are therefore already an accepted part of the CVI survey regime and were considered a welcome improvement over the estimated rut depths obtained during the CVI survey. It is further noted that machine CVI rut measurements are required to have an accuracy of ±2mm for all measurements. This exceeds the current TTS requirement of 95% for all machine rut measurements to lie within ±3mm of the true rut depth. Given the difficulties that TTS systems have found in meeting this requirement on some test sites, the CVI requirement is probably very hard to achieve given current equipment and technology, and there appears is no accreditation system in place to test this.

5.2.3.2 Defects which are desirable to detect

The following defects were considered to be very important. The reliable detection of these defects was deemed highly desirable for any TTS system which is to be introduced:

- Settlement / subsidence

- Components of surface deterioration
  - Minor fretting
  - Polishing
  - Fatting up
- Distinction between wheeltrack and non wheeltrack cracking
- Distinction between surface and structural rutting

Almost all the respondents agreed on which defects were essential to detect if present, and most of the defects rated as desirable to detect were also common to all respondents.

5.2.4 ***Rutting***

There was no evidence in the consultation which suggested that the reliable measurement of rutting was less important on minor roads than it would be on major roads. The feeling appeared to be that although minor roads would perhaps rut less frequently than major roads, when rutting did occur it was very important and should be detected as early as possible.

It was proposed that the roads which were possibly most at risk of rutting were parts of the B network which carry substantial traffic, including HGVs, but have not had the benefit of a designed construction. These roads have often simply evolved over time, and were never meant to deal with the levels of trafficking to which they are currently subjected.

There was also no evidence that the existing rut measurements and methods of presenting rut data may not be the most appropriate method for assessing the transverse condition of the pavement. However, the possibility that rutting may not be the best measure was suggested by a few respondents, but these tended to be existing TTS users or suppliers, and when pressed they had no alternative measures in mind.

5.2.5 ***Longitudinal Profile***

No respondent, not already using and familiar with TTS data, mentioned longitudinal profile as an essential parameter to measure. This is probably because the respondents not using TTS are only vaguely familiar with what information can be obtained from longitudinal profile measurements. Several respondents did mention the need to monitor ride quality, but as this is not currently assessed in the CVI surveys it was not deemed an essential ‘defect’ to measure with TTS. Ride quality was mentioned as being of special concern in urban areas. However, as the survey vehicle performance is known to be sub-optimal, especially in terms of measuring longitudinal profile, in urban areas it is possible that the longitudinal profile measurements made in urban areas would be unacceptable, or at least the coverage reduced. However, this would depend on the longitudinal profile wavelength considered to be most closely related to ride quality (and pavement condition) in urban areas.

In the UK longitudinal profile is currently used to express the evenness of the pavement at three different wavelengths. The longest wavelength examined (30m) is possibly closely related to settlement/subsidence and also road shape. It is this measurement which would be most problematic to measure in an urban environment. The shorter wavelengths (10m and 3m) would be less degraded when measured in such an environment, and may contain ride quality information of sufficient accuracy to be of use.

Even though few respondents said that longitudinal profile was essential to know about, the following should be considered:

- Settlement / subsidence was mentioned as a defect in the ‘desirable to know about’ category. This is possibly related to longitudinal profile, and may be detectable in the wheelpath

- An analysis on a small dataset provided by the SRMCS suggested that poor longitudinal profile was affecting more of the local roads network than rutting
- All respondents rated rutting as being a defect which was essential to detect
- It therefore seems that if rutting is essential to detect, and data suggests that longitudinal profile defects are affecting more of the non-PRN than rutting, then these longitudinal profile defects should be classed as being essential to monitor.

However, relating these longitudinal profile defects to any of the defects assessed in the current CVI condition surveys is not straightforward.

As well as providing information regarding the pavement condition from an engineering viewpoint the longitudinal profile information can also be used to provide information regarding the comfort of the road user. The importance of this should not be underestimated. If a key objective of pavement maintenance is to provide improved roads from the point of view of the user, for whom comfort is very important, then it is clear that longitudinal profile is the most suitable method of assessing this.

The fact that longitudinal profile can perhaps be used to assess the road condition in these two very important ways makes it even more important to develop methods in which the data can be measured and utilised in local road environments.

5.2.6 ***Defect / Road type relationship***

The importance of various defects on different road types was considered:

- Rutting and cracking were viewed as the most important defects on more highly trafficked roads
- The reliable detection of edge deterioration and wearing course defects were seen as most important on minor, or less trafficked roads

The fact that the classification of a road (A, B, C, u/c) in many cases bears little or no relation to the importance of that road to the local network, or the levels and types of traffic carried by the road was mentioned by several respondents. This perhaps raises the idea of introducing a ‘suitable for TTS’ classification which would be determined independently of the roads current A, B or C status.

It is also important to realise that simply because a road is classed as a C road it does not automatically follow that it is any more or less trafficked than a B road. It is also the case that just because it is possible and practical to perform a TTS survey on most B roads, it may not be possible to do this on all B roads. Or that just because it is possible to survey most C roads using TTS, there may well be some B roads which cannot be surveyed using TTS.

5.2.7 ***Data Presentation***

Questions were also asked regarding the ways in which the experts would like access to the data, and the levels of detail that would be required in order to perform various tasks. The key responses were:

- Traffic light based data handling system similar to that used in Scotland seen by most respondents as a good idea as a broad brush approach
- Availability of more detail (than in the simple traffic light approach) would be needed to help targeting of resources

The feeling from the majority of responses was that maintenance engineers require a priority listing of roads in need of treatment, that can be easily described and explained to local budget holders, but which can also be used to provide network performance statistics.

However, issues regarding the way in which the data is presented are similar no matter what method is used to collect the data. Whether the data is collected using TTS methods, or visual surveys, the end users want the same outputs and details and so, whilst it is important to ensure that the TTS outputs are compatible with the UKPMS systems, the fact that this is not directly a TTS issue should be remembered. This issue highlights the need for improved communication and collaboration between those involved in the implementation and development of TTS and those involved in the development of the UKPMS.

5.2.8 Apparent discrepancy between TTS BVPI and other TTS Condition Indices

The TTS Best Value Performance Indicator (BVPI) is derived from a single condition index (TTS96). TTS96 is an indication of the percentage of the surveyed network with a TTS condition index of 100, and for TTS surveys the condition index is set to 100 if any of the defects examined exceed certain thresholds. There is no middle ground with the TTS condition indices: they are either 0 or 100.

The same defects which are used to calculate TTS96 can also be processed by UKPMS to provide various additional condition indices, such as the Structural Condition Index shown on the maps in Section 6.5.

There is conflict between the use of these condition indices for assessment of pavement condition and the TTS96 indicator used for BVPI purposes. For example, it has been observed that data may trigger the BVPI thresholds, but may only produce low values for the Structural Condition Index. Conversely, examples exist of data giving very high Structural Condition Indices which do not exceed the BVPI thresholds.

Therefore authorities will possibly be faced with a set of mixed messages whereby lengths of their networks will be shown to require treatment using one indicator, but will be reported as having a satisfactory condition using another, equally accepted set of criteria. Authorities will than have to decide whether to focus on improving or maintaining their BVPI ratings, or maintaining the network in ways which may have little or no effect on the BVPI.

It is important that issues such as this, and the above issue concerning the presentation of the data and the availability of appropriate levels of detail are addressed carefully prior to the introduction of the surveys. Failure to do so will lead to authority engineers and other data users becoming confused, frustrated and dismissive towards TTS data.

5.2.9 Other Issues

A number of other issues were raised by respondents that did not fall into any defined area. These included:

- Some respondents would prefer TTS to replicate CVI. However others regarded this to be pointless, and stated that the opportunity should be taken to explore new measurements
- Other parameters mentioned as being of interest or useful to assess included:
    - Surface type
    - Noise due to surface/tyre interaction
    - Condition of line markings
    - GPR data

The dispute over whether an automatic system should replicate the manual system which it is replacing is common to almost all issues of automation.

Algorithms which identify the surface type of the pavement, and predict the noise levels due to the tyre/road interaction have recently been developed by TRL for use on the HA network. Such methods may be useful on local roads. Work is also currently ongoing at TRL into the testing, development and use of GPR data and traffic-speed line monitoring equipment.

5.3 UK expert consultation – Summary

In summary, there was no definite opposition to the principle of TTS being used on local roads, but there were deep seated concerns regarding the timescale and whether or not the technology was sufficiently developed and understood to allow the introduction of these surveys as soon as 2005.

If TTS is to meet the requirements of the experts consulted during this study the system must be able to reliably and accurately detect the following defects:

- Essential defects:
  - Rutting
  - Cracking
  - Edge deterioration
  - Surface deterioration

Additionally, it would be highly beneficial and desirable if TTS could detect the defects in the following list:

- Desirable defects:
  - Settlement/ subsidence
  - Components of surface deterioration
  - Distinction between wheeltrack and non wheeltrack cracking
  - Distinction between surface and structural rutting

It must be noted however, that in the current CVI and DVI approaches, there is no facility available to distinguish between surface and structural rutting.

Even if and when the TTS vehicles and systems have solved the problems of detecting the defects on the road, there remain some key concerns about the practical viabilities of performing TTS on the local road networks:

- The practical issues with carrying out TTS on urban residential roads would make daily survey lengths very small
- There is a need for more accredited survey vehicles to cover the non-PRN

6 Data Analysis and Comparison

As stated in Section 2, the second phase of this project has undertaken a small-scale data analysis exercise to assess the usefulness and appropriateness of TTS survey data against data collected using existing visual surveys. This exercise has utilised data from a number of sources, as summarised in Section 6.1 and assessed the data in two ways. Firstly as a 'network wide' analysis and secondly as a set of 'site specific' investigations.

The 'network wide' analysis has compared the lengths of road within the dataset which were deemed by the two different survey methods (TTS and visual) to exhibit key defects.

In the site specific investigations, a selection of sites which were highlighted in the visual inspection as containing particular defects have been investigated in detail to determine how the machine based surveys had assessed the pavement, and to see whether or not the machine survey results bore any relation to the visual data.

6.1 Data sources

The data used for the comparison between visual and machine surveys was supplied by a number of local authorities, as shown in Table 3. This data consists of Coarse Visual Inspection (CVI) and machine (TTS) survey data. Further data, which was used only in the site level comparison, was also taken from previous analyses of manual (CHART) and TRACS surveys carried out on selected sites on the Trunk Road Network.

Authority	CVI data	TTS (or machine) data	Length of data (km)
Kent	Y	Y	350
Hammersmith and Fulham	Y	Y	29
Camden	Y	Y	28
Harrow	Y	Y	47
Haringey	Y	Y	27
Sutton	Y	Y	12
Cornwall	Y	Y*	25
		Total length-km	517

Table 3: Sources of data used in data analysis and comparison. (*Machine data from Cornwall was based on MRM surveys not TTS and was excluded from Network level analysis leaving 493km of TTS data)

It is noted that for the machine data provided by the local authorities the machine based surveys were not necessarily carried out with equipment conforming rigidly with the TTS requirements, and hence these were not all fully TTS accredited surveys. However it has been assumed that the machine data was of sufficient accuracy and comparability with TTS to allow satisfactory conclusions to be drawn from this comparison of machine and visual surveys that could be related to TTS.

An observation that was made immediately upon commencement of the comparison was that, although the data from both CVI and TTS surveys is recorded and stored as "hmdif" files, the hmdif files were not always provided in a format that could be considered as "standard". For example, some TTS files were delivered such that repeat identical section identifiers existed within the data files, which affected the loading of the survey data and resulted in the need for manual manipulation of the data files. The need for consistent file formats is therefore stressed.

It was also found that the availability of an adequate description of the network from which the data has been supplied is essential to enable successful importing of the data into the UKPMS compliant PMS used in the data analysis. Furthermore consistent naming conventions also aid in the data comparison. It was found that data from one survey type (e.g. CVI) often contained a certain section naming format, whilst the data from the other survey type (e.g. TTS) would use a slightly different format, although the section name would be fundamentally similar for both data types. This complicates automatic alignment and comparison of the survey data.

6.2 Data analysis

In order to compare the results of TTS and CVI surveys it was first necessary to process the data such that all defect observations were aligned correctly according to section and chainage. This was done using bespoke software adapted to the task of reading the UKPMS hmdif format data files, and Microsoft Access to align the data. Once correctly aligned the data was exported for analysis using Microsoft Excel.

Some of the defects investigated, such as Whole Carriageway Major Cracking, and Wheelpath Rutting, were directly comparable as, in theory, exactly the same parameter was measured by both systems. For other defects, such as CVI Edge Deterioration, there was no direct equivalent TTS measurement, and so the relationships between the CVI defect and proxy TTS measurements were investigated.

6.2.1 Reference data assumptions

The analysis concentrated on comparing the TTS reported defects against the CVI reports, taking the manually collected CVI data as the reference.

It is noted that the CVI survey data is not necessarily “right”, but no independently assessed reference dataset was available against which both TTS and CVI data could be assessed. The CVI survey is the currently accepted system, and therefore by comparing the TTS data against the CVI results it is possible to obtain some indication of how acceptable the data from the proposed TTS surveys will be.

The severities of CVI defects are classified as defined in Appendix 2 of the UKPMS Visual Survey Manual, and are shown in Table 4. For the purposes of the analysis is was assumed that where defect data did not exist at any chainage in the CVI data file, but where that defect had been recorded at some point in the entire survey, then that defect had been included in the survey but was not present at that chainage. These instances were assigned to Category 0.

	Extent of Defect	**Description**
Category 0	<5%	No Defect
Category 1	5% - 20%	Local
Category 2	20% - 40%	Partial
Category 3	>40%	General

Table 4: Thresholds chosen for categorisation of CVI data.

In order to provide a better comparison between the CVI and the TTS data, thresholds were applied to the data from the machine surveys. These thresholds categorised the severity of the defects as 0, 1, 2 or 3 following the CVI categorisations, with Category 3 representing a serious defect, and Category 0 representing no recorded defect.

For the TTS data the thresholds used to determine whether a defect should be Category 0, 1, 2 or 3 have, where possible, been based on those used by the Scottish Road Maintenance Condition Survey (SRMCS) and are shown in Table 5. However some parameters are not used in the calculation of the SRMCS Condition Indices and hence there is no existing guidance on the values for threshold levels for these parameters on the non-PRN. Also, the SRMCS uses only a three level categorisation regime and not the four levels used in this study to be directly comparable with CVI data. In these cases the thresholds selected have been chosen based on experience gained in dealing with threshold settings for use on the HA trunk road network. It is not proposed that these thresholds should be adopted for use on local roads without further research being undertaken to confirm their suitability – they are valid for this study only.

	Cracking	Rutting	LV3	LV10	LV30
Category 0	0*	0*	0*	0*	0*
Category 1	0.15*	6*	1.5*	7*	7.5*
Category 2	0.5*	11	4	21*	187*
Category 3	2*	20	10	56*	300*

Table 5: Thresholds chosen for categorisation of TTS data. Threshold values have been based where possible on those used by the SRMCS. Threshold values marked with an asterisk (*) are those which were chosen based on existing TTS guidance for Principal Roads (IAN 42/02).

6.3 Network Analysis – Frequency of Defect Detection

The 'network wide' comparison of TTS and CVI data assessed the frequency at which each selected CVI defect occurred in the dataset, and compared this with the frequency of occurrence of each selected TTS defect within the same dataset.

The frequency at which each CVI defect occurred at each of the severity categories can be seen in Table 6, and the frequency of occurrence of the directly comparable TTS defects of rutting and cracking are shown in Table 7.

		Category			
Total records: 49326	**CVI Defect Codes**	**0**	**1**	**2**	**3**
Left Edge Deterioration	BLED	90.21	1.66	2.03	6.09
Right Edge Deterioration	BRED	96.99	0.63	0.65	1.74
Carriageway Major Cracking	BCKJ	93.34	0.95	0.92	4.79
Transverse / Reflection Cracking	BTCK	96.57	0.01	2.39	1.04
Surface Deterioration	BSDE	94.01	0.91	0.59	4.49
Wheelpath Rutting	BWTR	98.86	0.02	0.01	1.11
Major Fretting	BFEJ	77.71	12.43	4.09	5.77
Settlement / Subsidence	BSES	98.27	1.55	0.12	0.05

Table 6: Frequency of occurrence of defect severity in CVI dataset.

		Category			
	TTS Defect Codes	**0**	**1**	**2**	**3**
Cracking	LTRC	89.96	3.99	4.57	1.49
Rutting	LLRT	50.12	27.35	13.04	9.49

Table 7: Frequency of occurrence of defect severity in TTS dataset.

The four letter defect codes shown in Table 6 and Table 7 are the identifiers used by the PMS databases and the engineers to describe the defects.

Figure 1 shows a graphical representation of the Cracking and Rutting data from the two data sources.

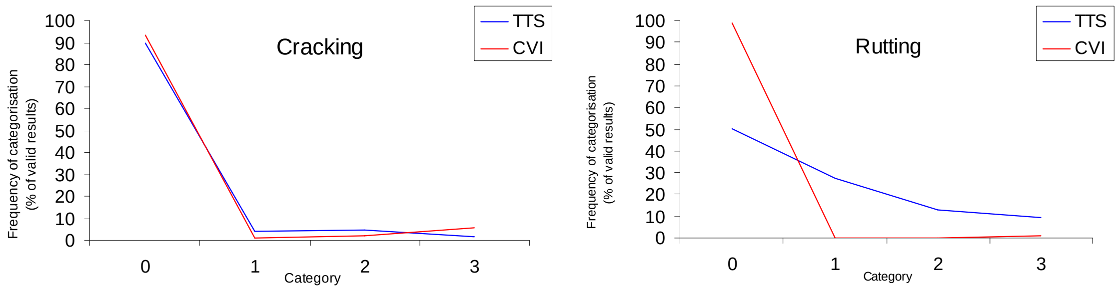


Figure 1: Frequency of reporting cracking and rutting defects as each category. Left graph shows Whole Carriageway Major Cracking defects measured using TTS and CVI methods. Right graph shows Wheelpath Rutting defects as assessed during the TTS and CVI surveys.

It is clear from Table 6, Table 7 and Figure 1 that both the CVI and the TTS surveys classify the majority of the network as being in Category 0, or not defective. However, the categorisation of those areas classed as defective (1, 2 or 3) shows differences between the two survey methods. Figure 2 re-plots Figure 1, but with Category 0 removed.

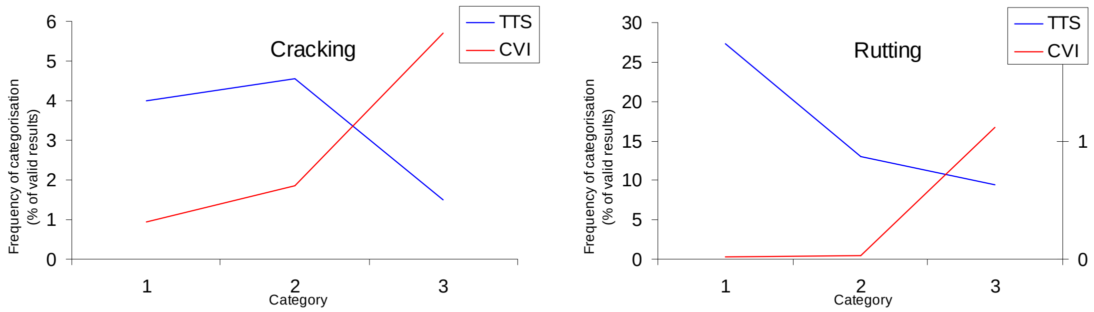


Figure 2: As Figure 1 but with removal of Category 0.

It can now be seen that the CVI surveys tend to report significantly more instances of the higher category defects than the lower category defects. This is not the case with the TTS surveys where, generally, there are more occurrences of Category 1 defects than Category 2, and very few Category 3 defects.

Although this difference in characteristic behaviour between the CVI and TTS survey data may be contributed to by the selection of the threshold levels for the TTS data, it is felt that this also indicates the sensitivity of CVI to recording severe defects. Hence inspectors might not record defects unless they are clearly present, and these would inevitably be observed over reasonably long lengths. This would lead to Category 1 and 2 defects being recorded less frequently.

6.4 The Road2000 Network Comparisons

The London Boroughs have recently been operating TTS surveys in parallel with CVI surveys. This has proved to be a very valuable exercise and has provided some very interesting information.

Maps were produced which displayed the Structural Condition Index (SCI) of individual boroughs as calculated using both TTS and CVI data. A short comparison study has been performed using a sample of these maps (Camden, Hammersmith & Fulham (Figure 3), Harrow, Sutton).

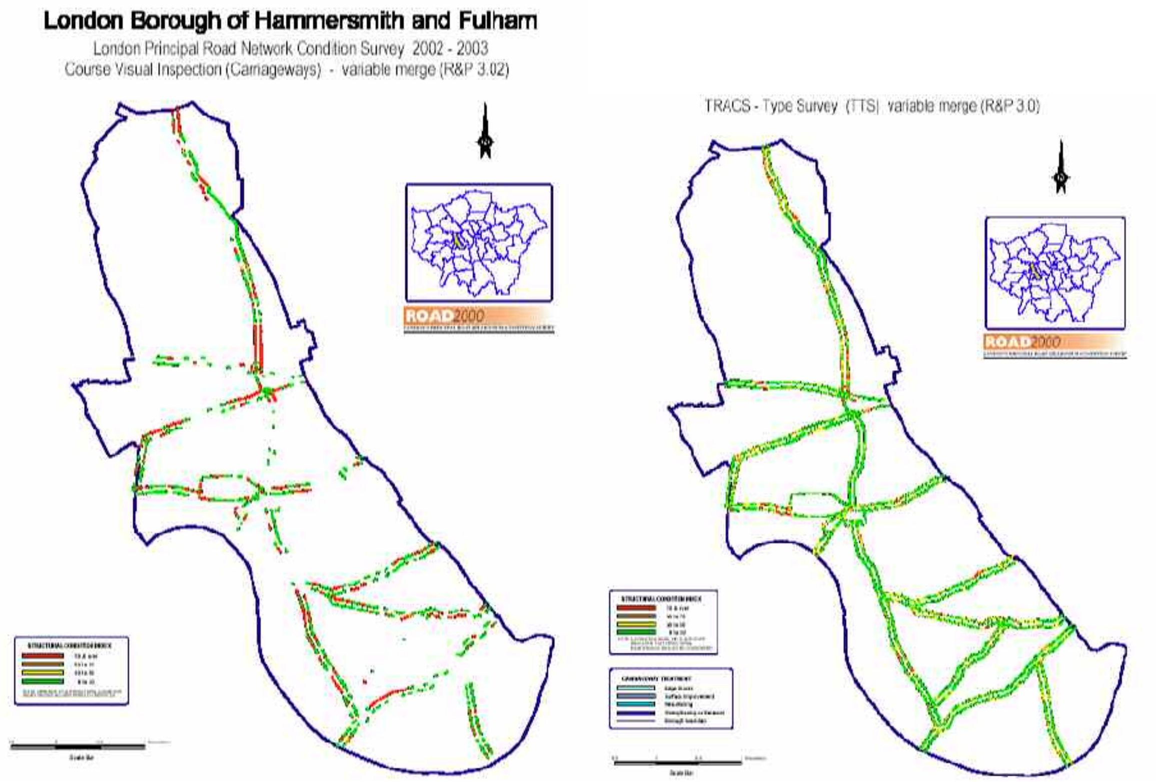


Figure 3: Example of maps produced by London Boroughs showing SCI as calculated using CVI data (left) and TTS data (right). Maps show London Borough of Hammersmith and Fulham, and are reproduced with their kind permission. © Crown copyright. All rights reserved. L.B. HAMMERSMITH & FULHAM Licence No. LA100019223 2004.

The most striking feature of the maps is the apparent difference in coverage between the TTS and CVI surveys. It has to be assumed that the CVI surveys did in fact survey the same network as the TTS, but where no defects were recorded, no SCI was calculated. A further observation is that far more variation can be seen in the SCI categories shown on the TTS maps than on the CVI. That is, the TTS maps seem to contain a distribution of green, yellow, amber and red subsections. This distribution seems to follow the expected pattern of there being more green than yellow, which is more common than amber, which in turn seems more prevalent than red subsections. The CVI maps seem to contain almost exclusively green and red subsections, and on some of the maps there appears to be as much, if not more, red than green. If the parts of the network which do not appear on the CVI map were also assumed to have no defects then the majority of the networks would appear green, but there are very few subsections which are anything other than sound or significantly deteriorated. This polarisation of the CVI results suggests, as has been observed in the other network comparisons, that the CVI inspection is less sensitive to detail.

The final feature of note is the way in which the two surveys categorise the networks:

- There are many areas where both the TTS and CVI surveys classify the SCI as being good, or green

- There are areas where both maps show the road as being in poor condition (red / amber)
- There are areas where the CVI shows red, but the TTS shows green
- There are no significant lengths (other than a few isolated spots) where the TTS shows red and the CVI shows green and therefore it is apparent that there are few areas where maintenance investigation would be triggered as a result of incorrect TTS data giving false positive reports of defects.

6.5 Network Analysis – Relationships between TTS and CVI defects

The frequency with which various TTS defects were reported in the presence of selected CVI defects was investigated using all the available data. This investigation looked not only at the presence, but also the severity of the defect.

Again it must be remembered that although the CVI results are used as the reference data they are not necessarily correct, and would not necessarily agree with an independent reference standard. The relative accuracies and reliabilities of the TTS and CVI methods depends to some extent on the particular defects being assessed. For example, research has shown that the automatic crack detection systems, as used on TTS vehicles, tend to underestimate the amount of pavement cracking, particularly when the cracking is longitudinal in nature. It is therefore fair to assume that the CVI surveys will generally provide a more accurate set of cracking data, and that the use of the CVI data as a reference set is sensible.

Conversely however, it is known that the CVI assessment of rutting is less accurate then the TTS rut measurement in the majority of cases. Therefore the use of CVI data as a reference when comparing rut measurements is justified only by the fact that the CVI is the currently accepted method.

6.5.1 CVI Carriageway Major Cracking (BCKJ) – TTS Cracking (LTRC)

Table 8 contains data regarding the reporting of different categories of TTS cracking in the presence of different categories of Cracking as reported by CVI surveys.

	TTS reported Cracking Category				
CVI Cracking Category	**0 (%)**	**1 (%)**	**2 (%)**	**3 (%)**	**TTS total (%)**
0	92	3	4	1	100
1	89	2	6	3	100
2	71	11	14	4	100
3	55	16	21	8	100

Table 8: Frequency of occurrence of TTS measured cracking of different categories in the presence of CVI detected cracking of different categories.

Each row of data in Table 8 shows the frequency of reporting of different severity categories of TTS crack data for an individual category of CVI data. The percentages are expressed as the percentage of times any particular CVI category was reported, and hence the sum of the TTS reports for Categories 0, 1, 2 and 3 should equal 100 for each of the CVI Categories 0, 1, 2 and 3.

So, for example, on 92% of the occasions when the crack severity as recorded by CVI was Category 0, the TTS reported cracking was also Category 0. Over 3% of these lengths (where the CVI reported cracking was Category 0) TTS recorded Category 1 defects, on 4% of these lengths Category 2 defects and on 1% of these lengths Category 3 defects were reported by TTS.

A number of conclusions can be drawn from examination of the data contained in Table 8. Most notably, and encouragingly, the TTS has a very low rate of false positives. That is there are very few instances (8%) when the TTS reports a cracking defect at a location where the CVI survey does not. It is also apparent that as the severity of cracking detected by the CVI survey increases, so too does the likelihood of the TTS also reporting cracking, and so too does the likelihood of the TTS reported cracking being of a higher frequency.

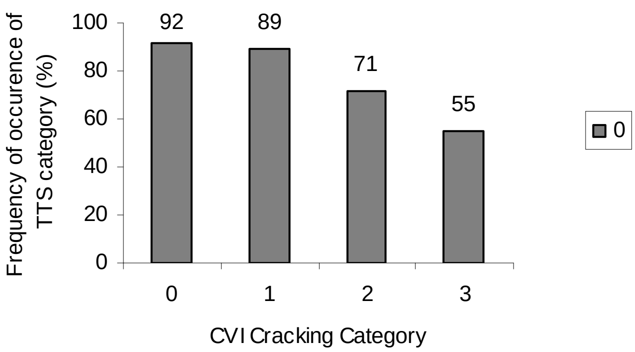


Figure 4: Frequency of occurrence of TTS measured cracking of Category 0 in the presence of CVI detected cracking of different categories.

These results can also be presented graphically as in Figure 4. This shows column 2 of Table 8 plotted against column 1. Figure 4 indicates how often TTS reports Category 0 cracking when CVI reports cracking of different severity Categories (0, 1, 2, 3). This illustrates the point that as the severity of cracking reported by CVI increases, the chance of the TTS reporting cracking of Category 0 decreases. However, even when the CVI data is reporting Category 3 cracking – the most severe – the TTS still reports Category 0 cracking 55% of the time.

Figure 5 shows columns 3, 4 and 5 of Table 8 plotted against column 1. This shows the distribution of cases where the TTS reports cracking at the three different defect levels of severity, compared with the CVI defect levels. Again it can be seen that at locations where the CVI surveys report more severe cracking, the cracking severity reported by TTS tends to increase.

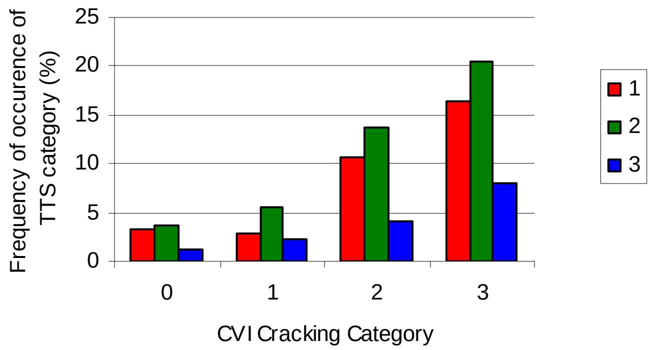


Figure 5: Frequency of occurrence of TTS measured cracking of different categories in the presence of CVI detected cracking of different categories.

Also seen is the tendency for the TTS reported severities to be lower than the CVI reported severities. It is not possible from the current data to determine unambiguously the reasons for the lower level of reporting in TTS. The fact that even where CVI reports Category 3 cracking the TTS is more likely to report Category 1 or 2 suggests that the CVI inspection may over estimate the severity of the defect. However, similar behaviour would result from a low level of sensitivity in the TTS crack detection system. It is noted that a low level of sensitivity in TTS has been observed on fine textured surfaces in TTS accreditation tests.

6.5.2 CVI Rutting (BWTR) – TTS Rutting (LLRT)

Table 9, below, contains data regarding the reporting of different Categories of TTS rutting in the presence of different categories of rutting as reported by CVI surveys.

It must be stated that the methods of assessing and categorising rutting are fundamentally different in the two survey types.

In the CVI survey the road is classed as exhibiting a rutting defect if the rut depth is greater than 13mm, and the category is then based on the length of the subsection affected by this rut depth. As rutting as deep as 13mm is unlikely to be present over very short lengths we would therefore expect Category 3 to dominate the CVI data which is not Category 0.

The TTS rutting categories are based on the average measured depth of the rutting over each subsection length.

The thresholds which have been used for categorisation of the TTS rut depths are 6, 11 and 20mm. That is if the rut depths are less than 6mm the rutting is Category 0, if the rutting is between 6 and 11mm the rutting is Category 1, rut depths between 11 and 20mm are classed as Category 2, and rut depths greater than 20mm trigger the Category 3 classification.

Therefore any TTS data reported in rut Category 0 or 1 would have had insufficient rut depth to trigger any CVI reporting of rutting, and could be considered as being effectively Category 0. Similarly, the threshold used for TTS Category 2 of 11mm is slightly less than the 13mm used in the CVI surveys, and so, even if TTS measured rutting in exactly the same way as CVI, a proportion of the Category 2 TTS rut categorisations would not be regarded as rutting in a CVI survey. Hence these differences in thresholds and methods of assessing the severity of the defect mean that care must be taken when assessing the comparative data presented in this Section.

It is immediately apparent that the data presented in Table 9 is incomplete. This is because the reports of CVI rutting of Categories 1 and 2 have been removed from the dataset as they were based on insufficient data (12 and 4 occurrences respectively, out of over 49300) and tended to, unrealistically, dominate the data.

	TTS reported Rutting Category				
CVI Rutting Category	**0 (%)**	**1 (%)**	**2 (%)**	**3 (%)**	**TTS total (%)**
0	22	43	33	2	100
3	46	27	22	5	100

Table 9: Frequency of occurrence of TTS measured cracking of different categories in the presence of CVI detected cracking of different categories.

Table 9 shows the frequency of reporting of different severity categories of TTS rut data for Categories 0 and 3 of CVI data. The percentages are expressed as the percentage of times any particular CVI category was reported, and hence the sum of the TTS reports for Categories 0, 1, 2 and 3 should equal 100 for each of the CVI Categories 0 and 3.

Figure 6 is a graphical representation of the first two columns of Table 9. This shows how often the TTS measured ruts were classified as being in Category 0 at locations the CVI rut assessment had classed as being either Category 0 or Category 3.

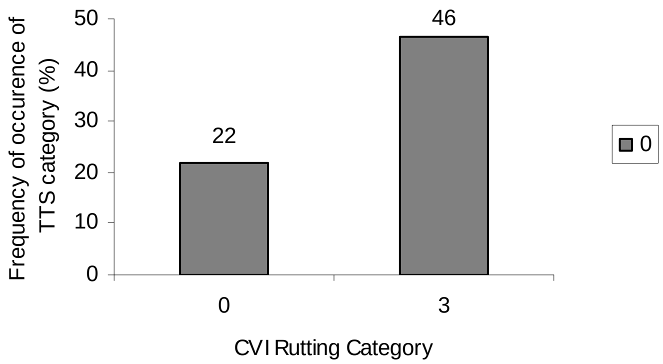


Figure 6: Frequency of occurrence of TTS measured rutting in the presence of CVI detected rutting (not CVI machine measured rutting).

It can be seen in Figure 6 that the TTS only reported Category 0 in 22% of the cases (10m lengths) that CVI reported Category 0. If it is assumed the CVI was correct (which is not necessarily the case) then this implies a high false positive rate in the TTS reporting of rutting.

However Figure 7, below, shows the frequency of occurrences of TTS Categories 1, 2 and 3 at locations where the CVI assessed rutting was either Category 0 or Category 3, and in this it can be seen that 43% of the time when the CVI rut assessment reports Category 0 the TTS rut measurement reports Category 1, which refer to rut depths below the threshold for CVI rutting. These are effectively correct, and leave approximately 35% of cases as false positives (in terms of CVI), categorised as Categories 2 or 3. However, 33% of these are Category 2, in which some cases (10m lengths) may have been below, or only slightly above the 13mm CVI threshold.

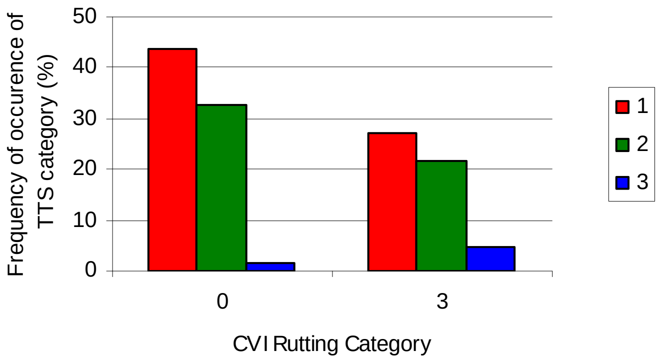


Figure 7: Frequency of occurrence of TTS measured rutting of Categories 1, 2 and 3 in the presence of CVI detected rutting (not CVI machine measured rutting).

In addition to the false positives, the false negatives, or the occasions when the CVI data reported Category 3 rutting, and the TTS data reported Category 0 or Category 1 rutting (which are effectively the same thing) must also be considered. These are shown at the right hand end of Figure 6 and Figure 7. It can be seen in Figure 6 that 46% of cases where the CVI rutting was Category 3 were classed as Category 0 by TTS, and Figure 7 shows that 27% were classed as Category 1. Category 2 TTS rut measurements made up 22% of Category 3 CVI rutting, with the remainder being classed as Category 3 by both systems.

While the different assessment methodologies, and incompatible thresholds have complicated the data comparison and analysis it is possible to draw some conclusions regarding the two sources of rut data.

The CVI data indicates that the visual inspections tend to report severe defects more frequently than TTS. This is probably a combination of the CVI survey itself, the categorisation procedure, and the effective single (13mm) threshold for CVI. This results in a low level of reporting of Categories 1 and 2 rutting (analysis of the data showed that there were only 12 reports of BWTR Category 1, and 4 of category 2).

An indicator that may cast some doubt on the CVI survey itself is the fact that the TTS tended to report a range of rutting (Category 0 (46%), Category 1 (27%), Category 2 (22%)) when the CVI survey reported Category 3. Assuming that the TTS is correct, which is likely in most cases given the results of accreditation tests of TTS systems, this behaviour suggests that rutting was present, but was often not as severe as the visual inspection judged it. This may be a result of variations in severity along the length of the survey being missed by the inspection (Section 6.7.4), or because the rutting fell in the range 14 - 20mm over long lengths, triggering Category 3 CVI categorisation, but only Category 2 for TTS.

6.5.3 Conclusions

The TTS data used in the network level assessment indicates that it (TTS) is typically a low false positive system. This is particularly noticeable in the lack of reports of cracking at locations where the CVI system had reported no crack defects, and also on the comparative maps provided by Hammersmith & Fulham (Figure 3) where there was a relative absence of red areas on the TTS map corresponding to areas on the CVI map which were coloured green. These maps also demonstrate the lower level of sensitivity to fine detail of the CVI surveys than the TTS. This is also illustrated in the distribution of defect categorisations: the reports from CVI surveys tend to either report category 3 defects, or no defect, while the reports from the TTS surveys are more statistically distributed, with more Category 1 than 2, and more Category 2 defects than Category 3. It is noted, however, that this stems to some extent from the selection of thresholds and the method of categorising the TTS data.

It is clear that there is not a strong correlation between reports of cracking defects made by the two survey types. While there are very few false positive reports of cracking by the TTS, there are a great many occasions when the TTS fails to detect any cracks at all, even where the CVI survey had reported category 3 cracking. Assuming the CVI data is correct, the TTS appears to have a lower level of sensitivity to cracking than CVI.

In the case of rutting the CVI is more likely to report high categories of rutting than TTS. This arises from the accuracy of the CVI survey itself and the method of categorising the CVI rut data, which results in low frequencies of reporting Category 1 and 2 rutting in the CVI data and lack of sensitivity in the CVI survey to changes in rut depths that may otherwise have resulted in lower reported categories.

6.6 Network Analysis – Indirect relationships between CVI Edge Deterioration and TTS defects

Where it was found that current TTS capabilities were incapable of identifying defects, which had been short-listed as essential to detect in the consultations, consideration has been given to alternative or innovative ways of using the data to provide useful information on these defects. One such area was the detection of edge deterioration.

The occurrences of edge deterioration as recorded by the CVI surveys were compared against occurrences of whole carriageway major cracking (as recorded by both the CVI and the TTS) and against occurrences of rutting and profile defects recorded by TTS.

Although it would initially seem strange to try and correlate whole carriageway cracking defects against edge deterioration, the CVI reports do not give details about wheeltrack cracking, and even the DVI reports only include the amount of wheeltrack cracking, with no indication of which wheeltrack the cracking was present in.

6.6.1 CVI Left Edge Deterioration (BLED) – CVI Carriageway Major Cracking (BCKJ)

Before assessing whether or not there was any meaningful relationship between TTS measured cracking and edge deterioration it was necessary to discover the strength of the relationship between cracking as measured by the CVI surveys and the presence or otherwise of edge deterioration.

	CVI reported Major Cracking Category				
CVI Edge Deterioration Category	**0 (%)**	**1 (%)**	**2 (%)**	**3 (%)**	**TTS total (%)**
0	94	1	1	4	100
1	96	0.5	0.5	3	100
2	91	0.5	2.5	6	100
3	87	1	2	10	100

Table 10: Frequency of occurrence of CVI measured cracking of different categories in the presence of CVI detected edge deterioration of different categories.

Table 10 contains the data regarding the frequency of times when different Categories of CVI cracking were recorded in the presence of different categories of CVI recorded edge deterioration.

Figure 8 shows the ways in which CVI reports of cracking are related to CVI reports of edge deterioration. The plot on the left of Figure 8 shows the frequency of occurrence of reports of Category 0 cracking in the presence of Categories 0, 1, 2 and 3 for edge deterioration. The plot on the right shows how frequent the reporting of cracking of Categories 1, 2 and 3 was in the presence of edge deterioration.

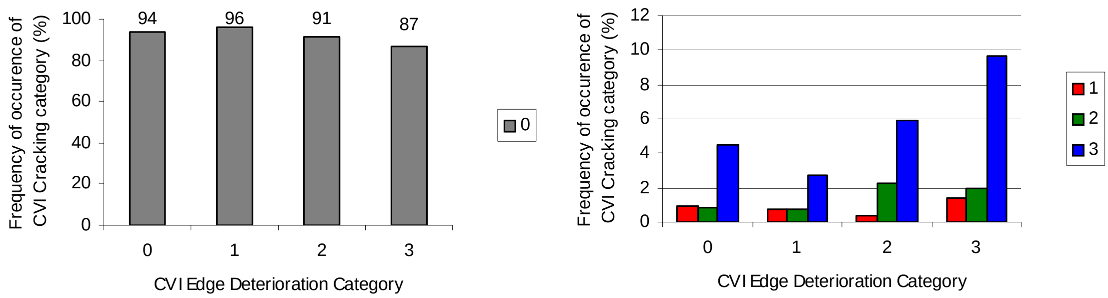


Figure 8: Frequency of occurrence of CVI measured cracking in the presence of CVI detected Left Edge Deterioration.

It can be seen that in the absence of any reported edge deterioration there is very frequently (94% of the time) no cracking reported, which possibly suggests a relationship between the two parameters. However it can also be seen that no cracking is reported by the CVI surveys 87% of the time that Category 3 edge deterioration is observed. This implies that the presence of edge deterioration is not necessarily associated with the presence of cracking (and vice versa). However, as the severity of the reported edge deterioration increases, there is an increased probability of detecting cracking in the same location, and this is likely to be reported at a higher level of severity.

As no strong correlation is apparent between CVI reports of edge deterioration and cracking this implies that, even if TTS was able to accurately replicate the CVI crack measure, this TTS cracking could not be used alone as a proxy indicator for the presence of edge deterioration, and hence additional information or interpretation would be required.

As the data presented in Section 6.5.1 shows, the TTS only detected the cracks detected by CVI in approximately 44% of the cases. Therefore a further complication arises from the fact that, as a result of TTS sensitivity, even if the detection of cracks by the TTS was to be used as a flag for further investigation for edge defects this would fail to be triggered over 50% of the time, as the cracks may not actually be detected by the TTS system.

6.6.2 CVI Left Edge Deterioration (BLED) – TTS Cracking (LTRC)

It was shown in Section 6.6.1 that the link between CVI reports of Whole Carriageway Cracking were only very weakly related to CVI reports of edge deterioration, and in Section 6.5.1 it was seen that the TTS reports of Cracking only sometimes agree with the CVI reports of cracking. In this Section the relationship between TTS reports of cracking and CVI reports of edge deterioration will be examined.

Table 11 contains the details of how often the TTS reports cracking of various categories in the presence of CVI reported edge deterioration of Categories 0,1, 2 and 3.

	TTS reported Cracking Category				
CVI Edge Deterioration Category	**0 (%)**	**1 (%)**	**2 (%)**	**3 (%)**	**TTS total (%)**
0	90	4	4.5	1.5	100
1	93	2.5	3.5	1	100
2	91	3.5	4.5	1	100
3	87	4.5	6.5	2	100

Table 11: Frequency of occurrence of TTS measured cracking of different categories in the presence of CVI detected edge deterioration of different categories.

The data shown in Table 11, shown graphically as Figure 9, indicates that, while there is a very slight correlation, there is no strong link between the detection of cracking using the TTS system and the reported presence of Left Edge Deterioration. This is as expected, given the findings of Section 6.6.1.

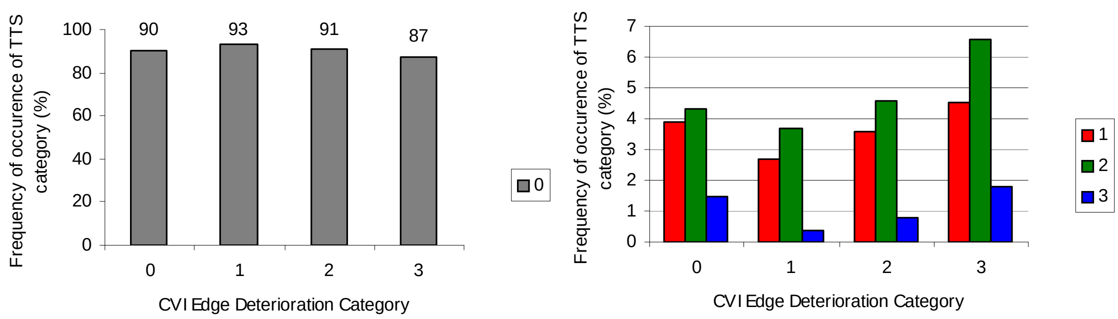


Figure 9: Frequency of occurrence of TTS measured cracking in the presence of CVI detected Left Edge Deterioration.

The distribution of TTS reported Categories of cracking hardly varies in the presence of different degrees of Edge Deterioration. Indeed the distribution of TTS reported Categories in areas with no reported Edge Deterioration is very similar to the Crack Category distribution where there is Edge deterioration. Again this suggests that the presence of cracking in a TTS survey could not be assumed to be associated with the presence of Edge Deterioration without additional information regarding the nature of the cracking. However, it should be noted that the cause of Edge Deterioration is not always cracking. It should further be noted that this analysis has used the measurement of whole carriageway cracking as the crack measurement from the TTS data, as information regarding the position of the detected cracks was unavailable.

While these results are in many ways expected, they are unfortunate as a strong link between TTS cracking and CVI edge Deterioration would aid in the detection of Edge Deterioration using TTS.

Clearly additional information giving details about the position of the cracking relative to the road edge would allow the cracking measurements to be used to determine the presence of edge deterioration more successfully, but this will not resolve issues associated with other (non cracking) causes of edge deterioration.

6.6.3 CVI Left Edge Deterioration (BLED) – TTS Rutting (LLRT)

As with the relationship between TTS detected Cracking and CVI reported Edge Deterioration it is apparent from the data in Table 12 and Figure 10 that there is no strong link between the detection of rutting using the TTS system, and the presence of Edge Deterioration.

	TTS reported Rutting Category				
CVI Edge Deterioration Category	**0 (%)**	**1 (%)**	**2 (%)**	**3 (%)**	**TTS total (%)**
0	52	26	13	9	100
1	38	35	15	12	100
2	47	27	14	12	100
3	48	29	13	10	100

Table 12: Frequency of occurrence of TTS measured rutting of different categories in the presence of CVI detected edge deterioration of different categories.

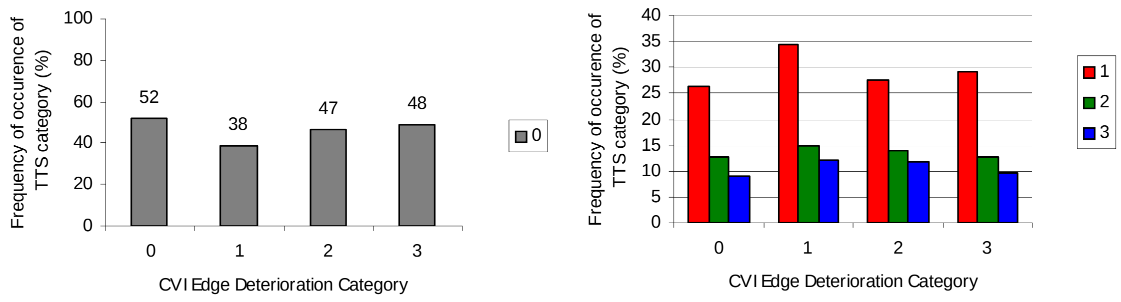


Figure 10: Frequency of occurrence of TTS measured rutting in the presence of CVI detected Left Edge Deterioration.

The ability to relate the position of the rut to the edge of the pavement would possibly improve the usefulness of rut measurements as a proxy method for detecting Edge Deterioration, as any rut within 50cm of the edge of the pavement would be classed as edge deterioration. Knowledge of the position of any rut relative to the edge of the road would also provide some indication of which roads were more likely to suffer from edge deterioration, as if the data showed that there was a large distance between the edge of the road and the rut then this would imply the road may be wide, and the edge of the road was rarely trafficked. A small rut-edge distance would imply a narrower road, on which the traffic may more frequently use the edge of the road, or even the verge.

6.6.4 CVI Left Edge Deterioration (BLED) – TTS Profile Variance Defects (LV3 and LV10)

Table 13 and Figure 11 show the frequency of occurrence of various categories of TTS 3m longitudinal profile variance in the presence of CVI reported Edge Deterioration. Table 14 and Figure 12 show the same information for 10m longitudinal profile variance. It can be seen that there is no apparent increase in the likelihood of measuring high levels of variance in the presence of edge deterioration and hence we again observe no distinct relationship at a network level between the presence of CVI detected Edge Deterioration and the TTS defects.

	TTS reported 3m Profile Variance Defect Category				
CVI Edge Deterioration Category	**0 (%)**	**1 (%)**	**2 (%)**	**3 (%)**	**TTS total (%)**
0	45	29	18	8	100
1	36	32	24	8	100
2	39	32	20	9	100
3	43	30	19	8	100

Table 13: Frequency of occurrence of TTS measured longitudinal profile defects (3m) of different categories in the presence of CVI detected edge deterioration of different categories.

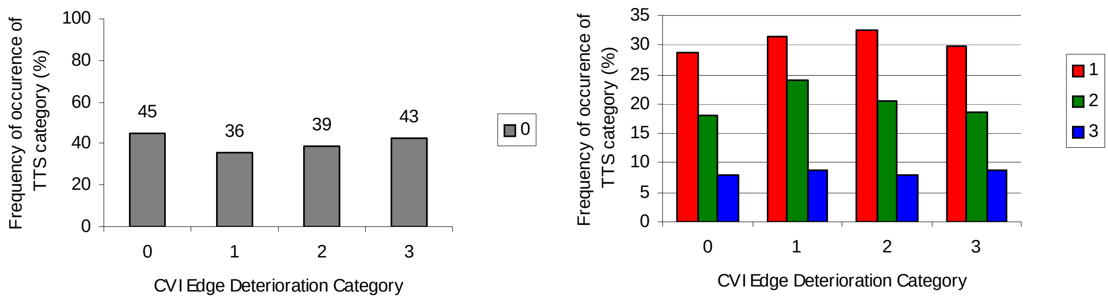


Figure 11: Frequency of occurrence of TTS measured 3m Longitudinal Profile Variance defects in the presence of CVI detected Left Edge Deterioration.

	TTS reported 10m Profile Variance Defect Category				
CVI Edge Deterioration Category	**0 (%)**	**1 (%)**	**2 (%)**	**3 (%)**	**TTS total (%)**
0	35	31	22	12	100
1	29	31	25	15	100
2	29	31	26	14	100
3	34	30	23	13	100

Table 14: Frequency of occurrence of TTS measured longitudinal profile defects (10m) of different categories in the presence of CVI detected edge deterioration of different categories.

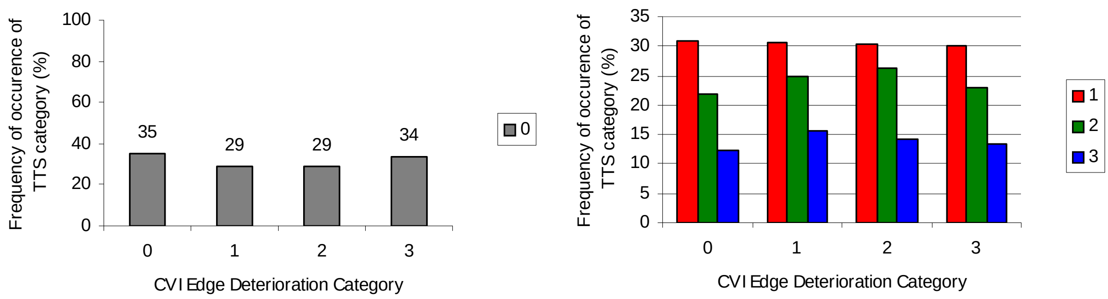


Figure 12: Frequency of occurrence of TTS measured 10m Longitudinal Profile Variance defects in the presence of CVI detected Left Edge Deterioration.

6.6.5 Conclusions

The data presented in Sections 6.6.1, 6.6.2, 6.6.3 and 6.6.4 show that the TTS defects cannot be used individually to reliably identify the presence of CVI recorded Edge Deterioration. However, at this stage of development it should not be assumed that combinations of defects would not provide some indication of the presence of edge deterioration. It is felt, given the poor relationship with individual defects, that this would at best provide a very rough estimate of the presence of edge deterioration, and therefore improved techniques of raw data processing would be more likely to achieve success.

6.7 Site level comparisons

The CVI records of all sites were investigated and a number of sites which were seen to exhibit key defects or combinations of key defects were selected. These sites were investigated in more detail to see how the detection of these defects varied between the survey methods (CVI or TTS).

6.7.1 Site 1: Harrow

The human and machine observed cracking and rutting measurements from this site – length 2.9km – were examined. Figure 13 shows how the CVI and TTS cracking categorisations compare along the site, Figure 14 shows how the rutting categorisations compare.

The raw TTS cracking and rutting measurements have also been included on the graphs.

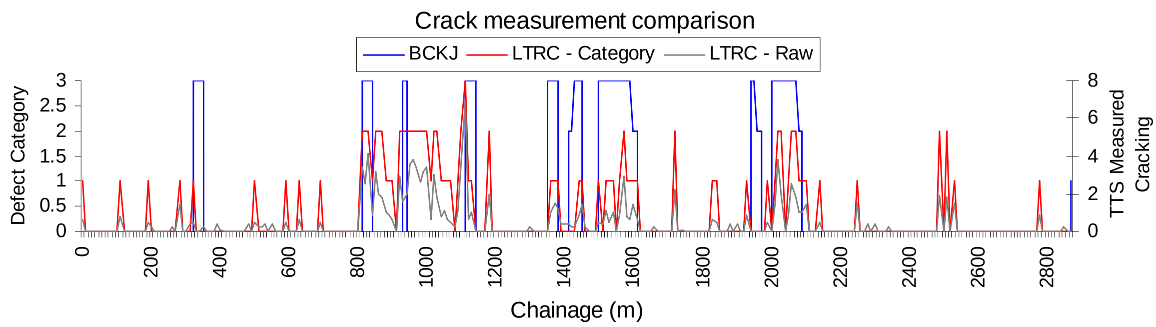


Figure 13: Comparison of cracking as detected by TTS (LTRC) and CVI (BCKJ) surveys along a 2900m length of the Harrow network.

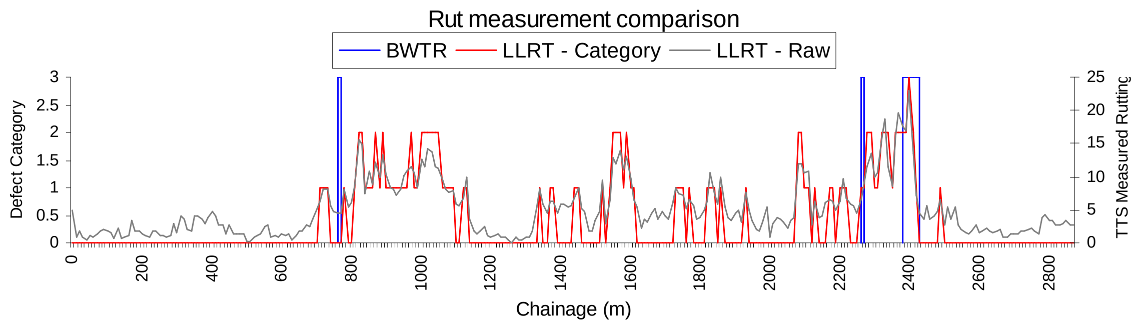


Figure 14: Comparison of rutting as detected by TTS (BWTR) and CVI (LLRT) surveys along the same 2900m length of the Harrow network shown in Figure 13.

A reasonable degree of agreement between the two crack measurement techniques is apparent (Figure 13), with the TTS system at least agreeing with the CVI survey on the location and presence, if not the severity, of all the CVI cracking. The data also show a number of places where the TTS detected cracking, usually in Category 1, where the CVI survey reported none. This may be because the CVI inspector did not think the cracks affected enough of the road to warrant recording.

There are several examples of this in the first 700m of the site. It can be seen in the raw data plot that the amount of cracking detected which has triggered these TTS reports of Category 1 cracking is very low, in many places only just greater than the TTS cracking threshold.

In addition, experience with current TTS crack detection systems have shown these to be susceptible to certain road surface features such as fretting, patching, potholes or road markings, all of which may be sometimes incorrectly identified as cracks. Access to the crackmaps produced by the system would allow a better understanding of what was causing the discrepancies between the CVI and TTS crack measurements.

The data shown in Figure 14 is less impressive. Here we see the CVI measured rutting (assessed manually and not using a machine) compared against the TTS measured rutting. It would seem from looking at the TTS data (assuming that the TTS is correctly measuring the rutting) that there was a reasonable quantity of category 2 rutting on this site, but the CVI has not detected this. The CVI reported rutting is always (on this site) either zero, or Category 3. As a positive feature, the one time the TTS data indicated a rut of Category 3 at approximately 2400m did coincide with the longest length of carriageway affected by rutting according to the CVI survey.

6.7.2 Site 2: Hammersmith & Fulham

A second site for study was chosen in the Borough of Hammersmith and Fulham. As before the different categories of cracking and rutting defects determined using TTS and CVI methodologies was compared.

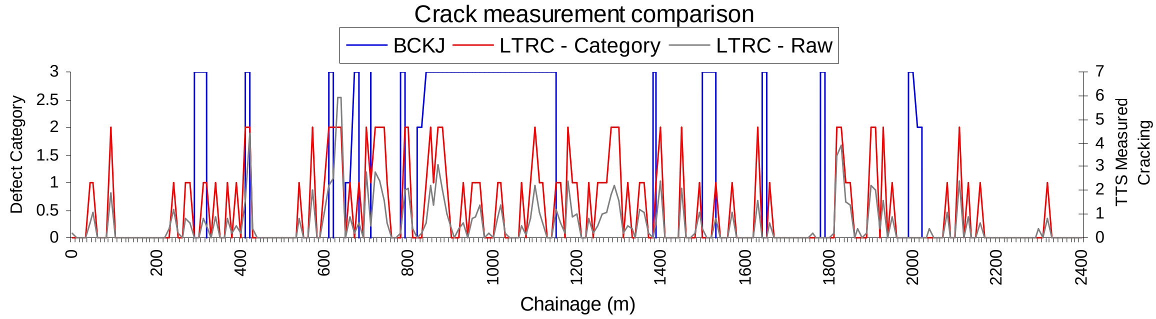


Figure 15: Comparison of cracking as detected by TTS (LTRC) and CVI (BCKJ) surveys along a 2400m length of the Hammersmith & Fulham network.

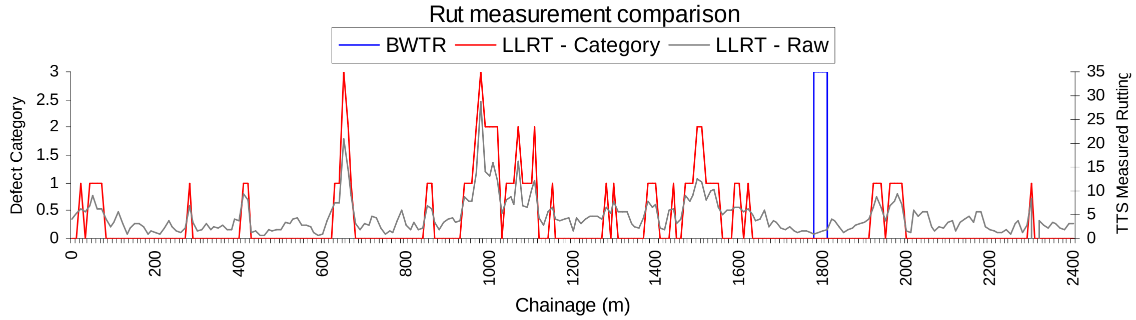


Figure 16: Comparison of rutting as detected by TTS (BWTR) and CVI (LLRT) surveys along the same 2400m length of the Hammersmith & Fulham network shown in Figure 13.

The data shown in Figure 15 and Figure 16 shows a much poorer agreement between the TTS and CVI surveys. There appears to be quite a lot of cracking along the site, but the two surveys seldom agree on the location, length or severity of the defect. Also, between 850m and 1150m the CVI survey reported a constant length of cracking of Category 3. The TTS survey along this length indicated a length of road which has some initially quite serious cracking (Category 2) which diminishes in severity and disappears for short intervals.

The comparison between the rut defect data in Figure 16 shows no correlation at all between the CVI and TTS surveys. In fact the only piece of rutting recorded by the human inspector occurs at a point where the raw TTS measured rutting is well below the Category 1 threshold. Elsewhere on the site (1000m) the TTS data indicates quite heavy rutting, but the CVI shows nothing.

6.7.3 Site 3 A404M (Trunk Road CHART Data)

Figure 17 shows the amount of cracking detected during a manual CHART survey, compared to the cracking detected during a vehicle based automatic survey. Manual CHART data was not available for all of the survey length as can be seen by the gap in the data towards the right hand end of the plot.

It can be seen that the TRACS cracking in the first 60% of the site agrees well with the CHART survey, but for the second half of the A404M there are large differences between the cracking detected using the two methods.

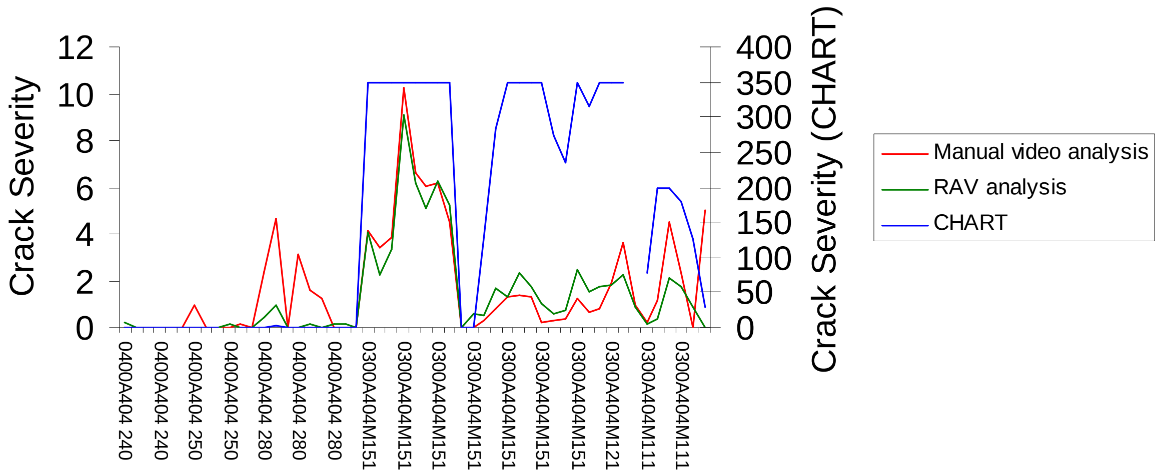


Figure 17: Comparison of cracking as detected by manual CHART inspection, and by RAV. Also shown is the manual analysis of video collected by RAV.

A later manual analysis of the video images which were used by TRACS to provide the automatic results matches the automatic results very well. This implies that the automatic results were in fact correct even though they were drastically different from the manual survey performed on site. This demonstrates some of the weaknesses of the visual inspection methodology. That is the inspections tend to over estimate the presence of any defects, and they fail to react to the change in severity of defects. In this instance it appears that the surveyor has measured the cracking in the middle of the site quite well, and has correctly reacted to the short length of un-cracked pavement. However, once the cracking has been seen to resume the measurements quite quickly revert to classifying the crack severity as being as bad as the previous cracked section, even though it would appear from the TRACS data, and the manual analysis of the TRACS data, that this is not the case.

6.7.4 Site 4 – A34 Rutting (Trunk Road)

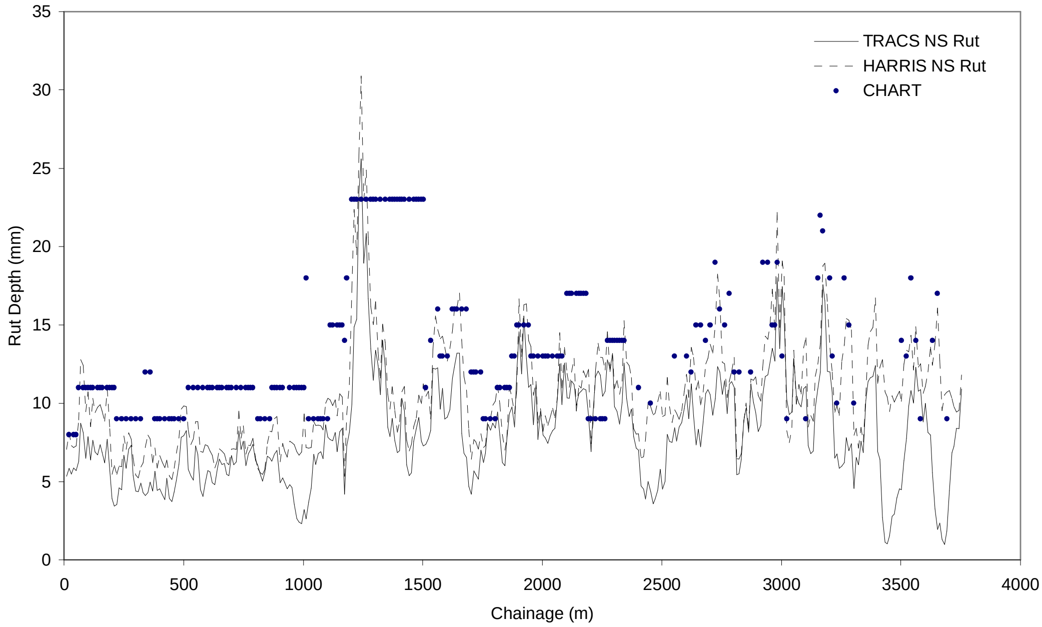


Figure 18: Comparison of rutting as detected by manual CHART inspection, and by machine based surveys carried out by TRACS and HARRIS.

Figure 18 compares TRACS and CHART measured rutting over a length of the A34. It can be seen that reasonable agreement is obtained between the survey methods. However, distinctly different behaviours are visible. The TRACS data varies continuously along the site, whereas the CHART survey reports reasonably consistent levels of rutting, especially over the first part of the site. This may be as expected because the rutting (TRACS) does not vary significantly and it is likely that the CHART inspector has considered the rutting to be constant and has not repeated his measurement over these lengths. However, if the rutting is examined between 1300 and 1500 metres along the site it appears that TRACS has made an under-measurement. Examination of the raw transverse profiles over this length showed that the CHART surveyor had failed to update his rut measurement. Instead of reassessing the severity of the rutting as he proceeds along the site and the rut depths diminish, he had continued the estimate of a rut depth of approximately 23mm, even though the true ruts had dropped to just above 10mm. This is probably because the initial measurement of 23mm was made quite soon after the rutting had obviously become suddenly worse, but then, once this was made, the depth of rutting declined less dramatically, and the ruts were still significant.

7 Conclusions and Recommendations

7.1 Immediate needs for TTS

As of April 2005 initial TTS surveys will be performed on the non principal road network. A consultation has been carried out with UK and international stakeholders to establish opinions and concerns regarding these surveys. There has been no specific opposition to the principle of TTS being used on local roads, but there were concerns regarding the timescale and the status of current technology to enable the introduction of these surveys as soon as 2005.

The summary results of the review phase are presented in Sections 4.3 and 5.3. It was generally agreed that in order to be acceptable to local maintenance engineers the surveys must be able to identify rutting, cracking, surface and edge deterioration.

Furthermore, even allowing for the fact that unclassified roads are unlikely to be included in the initial TTS work it is considered imperative that more accredited survey vehicles become available. The idea of accreditation of the vehicle driver and operator should also be explored as it appears anomalous that so much effort and expenditure goes into ensuring the vehicles and instruments meet stringent criteria, and yet no qualifications or training are necessary to conduct a survey.

In order to meet the minimum criteria established during the consultation with the UK-based experts research must be undertaken in the short term to ensure that the TTS vehicles used for the initial phase of the local roads surveys are capable of detecting edge deterioration. Consultation with the experts has suggested that the simple detection of edge deterioration, without any additional details regarding the nature or severity of the deterioration may be acceptable as a first step.

Analysis of data from TTS surveys and comparison with CVI records has shown that the presence of edge deterioration cannot be simply derived from alternative TTS measurements such as profile variance, as no correlation was observed between this measure and the CVI reported edge deterioration. Furthermore direct relationships between current measures such as cracking and rutting and edge deterioration were not observed. Therefore a ‘quick win’ solution, as is required for the introduction of TTS by 2005 will require a sophisticated combination of measures or the derivation of a method that utilises the raw data provided by the TTS system (e.g. transverse profile, longitudinal profile) to obtain new derived parameters.

The data comparison has shown that there are distinct differences in the level of accuracy and sensitivity of CVI and TTS rut measurements. The TTS measure of rutting is generally regarded as preferable to the manual method. Indeed, the UKPMS Visual Survey Manual recommends the machine measurement of rutting. Therefore the underlying assumption in the data comparison has been that there is more confidence in the machine measured rutting. However, it is not possible to say from the current data that a proportion of the higher levels of rutting in the TTS data actually arose from false positive measurements. The narrow widths of some roads means that there are no clear wheelpaths within which rutting should be measured, and this makes it harder to ensure that the data gathered is consistently located with respect to the road edge. This can bring in many problems with detecting verges, kerbs, gullies or road markings, which can all interfere with the rut measurements if not identified and dealt with in the data processing. For these, and other reasons the suitability of the traditional rut measurement for use on local roads has been questioned. Therefore two immediate areas of concern with the rut measurement are the confidence in the measure itself and its appropriateness as an indicator of condition on such roads. Work must therefore be undertaken to determine whether alternative indicators of condition can be obtained relating to the transverse profile of the roads. This is something which is being considered by initial research work on transverse profile.

The introduction of TTS will also require the derivation of appropriate indicators of condition. Examination of TTS and CVI data has shown that direct comparisons of condition indicators, using current techniques, is not straightforward even for the common parameters of cracking and rutting.

For the rutting datasets examined herein, distinctly different behaviour in the measurement and interpretation techniques results in significantly higher levels of category 3 rut depths in the CVI data than in the TTS data. This can be associated with the effective use of single thresholds in the CVI assessment and the coarseness of the CVI survey.

For cracking it is found that significant disagreements occur in the data. Commonly these arise from lower levels of reported cracking in the TTS data. Assuming the CVI measure of cracking is reasonable (for which only an assumption can be made given the current data) this highlights a need for improvements to the crack measurement. However, care would need to be taken in this area to ensure that the reasonably low false positive nature of the TTS is maintained. Such improvements have already commenced with the changes made to TTS systems to achieve accreditation. However, it is felt that the establishment of suitable thresholds for cracking (for indicators) may require further improvements and possibly a demonstration of the increases in accuracy through further controlled comparisons of the CVI and TTS data.

7.2 Longer term needs for TTS

There are several areas of TTS which have been earmarked for further research to enhance the survey performance on the non-PRN. The results of this initial review of TTS have suggested the following as potential research topics and directions.

*7.2.1 **Edge Deterioration***

While a ‘quick win’ approach based on existing measurements may satisfy the requirements sufficiently to allow the 2005 introduction criteria it may not satisfy the engineer’s requirements for the longer term. Therefore there will be a need to assess the quick win measure on the network and seek out opinions of practitioners regarding the usefulness and accuracy of the measure. This consultancy would also aim to determine what further detail, accuracy or robustness was required from the measure of edge deterioration.

Further research would then aim to develop a more robust method for the detection, quantification and classification of deterioration of the road edge. This may draw more strongly on the raw data capabilities of TTS systems, and consider the latest developments in image and profile collection.

*7.2.2 **Crack Detection***

The current automatic crack detection system has been described as a ‘hit and miss affair’. This has been shown to be true to some extent in the data assessment. Although the development of improved crack measures is also a short term requirement, it is recognised that the development of such systems is not limited to short term improvements. Whereas short term development should concentrate on improved underlying detection, longer term research and development must be undertaken to improve the accuracy and reliability of this system to a level which satisfies the requirements of the engineers who must use the data to plan and justify maintenance schedules. This must include the development of methods to distinguish between the different types of cracking, particularly longitudinal and wheeltrack cracking.

Because of the different levels of cracking reported by the automated and the visual surveys, the weightings and methods used within UKPMS to determine pavement condition may need to be altered.

Most of the more successful crack detection systems used currently are image based, and rely heavily on good, consistent light sources. The use of texture information could also be investigated but as cracks are often filled with dust and detritus this approach has obvious limitations.

7.2.3 *Longitudinal unevenness*

Because longitudinal profile or unevenness is not currently measured as part of a visual survey many engineers are unsure of what exactly it represents and tells them. Results obtained following the rollout of TTS in Scotland suggest that there may be a link between longitudinal unevenness and pavement condition. This comparison is not simple to derive from currently available condition data, which concentrates on visual condition. A comparison of, for example, variance and crack data will not necessarily demonstrate a relationship on the network level due to the fundamental differences between these two measures. The requirement, therefore, is to establish what the definition of condition is with regard to profile unevenness. This will inevitably be a combination of both engineering and user requirements. To establish such a definition will require both the selection of the appropriate parameter for profile and suitable levels for assessment.

Currently longitudinal profile measurements are made in only one wheel track, but for local roads, it may be appropriate to collect data from both wheel tracks. The usefulness of this two-track profile with respect to local road condition must be assessed and considered against the added cost and effort involved in obtaining the extra profile.

Previous work has investigated the use of changes in profile generated using a single laser to provide a method of observing structural deterioration between successive surveys. This work had successes, but was very susceptible to small errors in survey location referencing. The guidelines for using this approach are given in Volume 7 of the DMRB HD29. Due to the construction of the trunk road network this method was attempting to identify extremely small changes in profile. On the local road network the changes may be more significant and more straightforward to identify (given suitable locational accuracy). There may, therefore, be benefit in considering such approaches.

7.2.4 *Other visual defects*

The detection of ‘other visual defects’ was not classed as an essential feature of any TTS system in the initial stages. However the detection of ‘surface deterioration’ was classed as essential. Surface deterioration (which comprises minor fretting, polishing and fatting up) could perhaps be detected using a mixture of image and texture data. It is noted that a prototype fretting detection system is currently being implemented by the Highways Agency.

The detection and identification of each of the components of surface deterioration was rated as highly desirable, and so research into these defects should also be carried out.

7.2.5 *Skid resistance*

TTS do not measure the skidding resistance of the road surface directly. The use of texture data may however provide a useful proxy for high speed skidding resistance. The use of TTS gathered texture data will not remove the need for all SCRIM surveys, but should allow the improved targeting of resources to where they may be most useful.

Acknowledgements

The work described in this report was carried out in the Infrastructure Division of TRL Limited. The authors are grateful to Brian Ferne who carried out the quality review and auditing of this report.

The authors are also very grateful for the assistance and comments received from all the survey respondents and experts who have been very generous with their time and effort. Particular thanks must go to Gordon Prangnell and Adrian Wood (London Borough of Hammersmith and Fulham), Gary Fitch (Kent) and to Robert Epps (Cornwall) who very kindly supplied the data which were used in Section 6 of the report.

References

Ekins, JDK and Hawker, LG (2003), *TRACS Type Surveys for Local Roads: Scoping Study*

Ferguson, RA and Pratt, DN (2002), *Automated Detection and Classification of Cracking in Road Pavements (RoadCrack^{TM})*, Roads and Traffic Authority – New South Wales

Highways Agency (1994), *Design Manual for Roads and Bridges*, HD29/94, Part 2, Volume 7, The Stationery Office, Norwich

Highways Agency (2002), *Traffic Speed Condition Surveys: Revised Assessment Criteria, Interim Advice Note (IAN) 42/02*

Offrell P (2003), *Methods for measurements and analyses of cracks in flexible pavements*, Doctoral Thesis, Avd för Vägteknik, Kungl Tekniska Högskolan, Stockholm, Research Report TRITA-VT FR03:01 ISSN 1650-876X, ISRN KTH/VT/FR-03/01-SE

Offrell, P and Sjögren, L (2004), *Crack measures and reference systems for a harmonised crack data collection using automatic systems*, Unpublished

UKPMS Owners Forum (2001), *UKPMS Visual Survey Manual Version 1.0*, Chris Britton Consultancy

UK Roads Board (2003), *TRACS-Type Surveys of the Principal Road Network, Advice Note and Specification Version 1.0*, Report for the Roads Board, Chris Britton Consultancy

Appendix A. Overseas review – Initial questionnaire

1) In general, what experience do you (or your organisation) have in developing, conducting or analysing automatic road condition surveys at traffic speed?

2) On what types of road are these surveys carried out?

3) Which defects or road characteristics are measured routinely using automatic traffic speed surveys? Does this depend on road type (e.g. different defects on motorways and A roads)?

4) Do you intend to introduce routine measurements (using automated traffic speed surveys) of any other defects in the near future?

5) Are there any aspects of the automated condition surveys which have proved to be particularly problematic? Does this depend on road type?

6) In the UK measurements of transverse profile on Motorways and A roads are converted to rut depths. On the lower classes of road we are considering alternative methods of interpreting this data. We are also considering whether there might be better methods of interpreting the other data collected during the surveys (e.g. ride). Do you routinely use any "non standard" methods for analysing the data collected during the surveys.

7) Are you currently working on any new developments in the field of traffic speed automated condition surveys (either in the area of equipment or data processing)? For example the UK has been working on methods to use the surface texture of the pavement to predict noise levels generated at the pavement/tyre interface.

8) On lower classes of roads we note that deterioration of the road edge is a problem in the UK due to their width. Is this deterioration of interest in your country, and are you currently developing any new methods for data collection or data processing to automatically monitor the deterioration of the edge of the pavement?

9) We have also noted that the limited widths of narrow roads will affect the measurement of transverse profile and the calculation of rutting. Are you developing, or have you developed any alternative ways of examining transverse profile that are less affected by such problems?

10) Have you recently released, or are you aware of any recent publications that would be of interest to us when trying to deal with the issues of performing routine traffic speed automated condition surveys, an in particular on lower classes of road?

Appendix B. UK review – initial questionnaire

<u>A: About your network:</u>

The following questions are designed to provide an overview of the types of road which you deal with on a regular basis.

1. What percentages (rough estimate is good enough) of the network you are responsible for are urban/rural?
2. What percentages of the network you are responsible for that are A roads, B roads, C roads or unclassified roads?
3. Over what percentage of your network is parking at the side of the road common? Is this mainly in urban / suburban residential areas? Is this mainly on B roads, C roads or unclassified roads?
4. What percentage of your network is un-kerbed?
5. It is proposed that TTS be introduced on the non-principal network from 2005. It is likely to be a staged process, with a proportion of roads surveyed from 2005, increasing in later years. There is a need to determine the most appropriate of these roads on which implement these surveys from 2005. This may be decided by road shape/width/geometry. Do you have knowledge of the distribution of road widths and geometries on your network? Could this information be made available to us?

<u>B: About your experience with TTS:</u>

These questions are designed to let you express your feelings and thoughts about the concept of automated road condition monitoring:

6. Do you have any existing experience with TTS (or other automated visual condition) surveys? Have you had any particular difficulties with TTS surveys?
7. Do you have any objections to the principle of TTS?
8. Can you foresee any obvious advantages in TTS becoming more routinely used in your area on local roads?
9. Are you confident in the ability of TTS to provide you with the data you require?

<u>C: About your current methodologies</u>

The way in which you currently use the data from your visual condition surveys, and the defects about which you are particularly concerned are important, as this will aid in deciding how TTS could meet these needs and what extra data might be required from the TTS survey, as discussed in section D. The following questions also deal with the important issue of which defects you rate as essential from a condition survey, and your confidence in the ability of TTS to monitor these on the non-principal road network. They also give you the opportunity to specify defects or conditions which, whilst not essential, would be useful to know about

10. Of your existing DVI and CVI surveys, which are the defects that you would consider to be the most useful in terms of identifying areas of the non-principal network in need of more detailed investigation or maintenance. Your opinion in this may be lead by those defects that you consider of significance in engineering terms, those that you consider to have most significance for the road user and those that occur most commonly. We would appreciate points of view in any or, preferably, all of these areas.
11. Do you have an estimate of how much of your non-principal road network (by class) is affected by the above defects to such an extent that they are in need of more detailed investigation, or will be prioritised for maintenance as a result of these defects?
12. Do the above defects vary according to the type of road? E.g. is rutting very important on one type of road, and less important on another type? If this is the case, please give details of what

defects you feel to be most important on which types of road. Here you may consider “type” to be linked with classification, or you may feel that the classification is not the most appropriate way to distinguish between roads having different characteristics (e.g. width, trafficking).

D: About what TTS might offer:

The following parameters are included in the current proposals for TTS on the principal Road Network, and are reported in the surveys currently being carried out on the Scottish Road Network:

- Ride quality, reported as 3m longitudinal profile variance
- Rutting obtained from transverse profile measurements
- Texture depth (1 value for each wheelpath, and one value between the wheelpaths)
- Cracking (overall area and length in the wheeltrack)
- Road geometry (gradient, curvature and crossfall)
- The surveys typically also have a camera providing a forward facing video record of the survey for later analysis. However, this information is only provided if the authority requests it (it is not a required deliverable for a standard TTS survey)

The TTS survey data is therefore not necessarily directly comparable with the data collected in a current visual condition survey. The TTS data can often be related to the presence of these defects. For example texture depth can be related to high speed skidding resistance and the presence of fretting and fatting. Similarly poor ride quality may often be associated with the presence of subsidence or failed patches. However, it is recognised that this requires suitable interpretation of the data.

13. Are there any essential components of the CVI survey that you feel TTS will be unable to deliver? Does your confidence vary by road classification?
14. It is accepted that automatic surveys, in their current form, are not able to detect all defects identified by visual surveys. Which defects (if any) currently reported in a visual survey would you say are not essential in an automatic survey (i.e. do not significantly affect your current maintenance decisions)?
15. Are there any measurements/defects not in the above list (Question 14) that are, in your opinion, desirable, but not essential?
16. How would you make use of information regarding the defects in the desirable to know about category when making maintenance decisions?

E: Other machine surveys

17. What other survey methods do you employ (e.g. Scrim, Deflectograph) on your non-principal road network and on how much of this network?
18. If appropriate, will you continue to carry out deflection surveys after TTS begins? How is deflection (and other data such as Scrim as appropriate) used in your maintenance decision process on these roads?

F: Data presentation (UKPMS):

Clearly gathering the data is only one part of the condition monitoring process. How would you like the data to be analysed and presented to you so that your decision making process was helped? The following question allows you to express your feelings on how the data should be made available to you once collected:

19. How would you like the data to be presented to you for your use? Would you like a system similar to the one used in Scotland with road condition being marked as red, amber or green,

and maintenance priorities assigned accordingly, or do you feel you would want a more detailed reporting system, either with more than 3 possible condition indicators, or with information about several key parameters (rutting, cracking, texture) expressed separately?

G: Willingness to answer further queries:

Thank you very much for taking the time to complete this questionnaire. There may be a need to follow up your response with a few short questions relating more specifically to the measurement and assessment of edge deterioration and transverse profile. This would probably take the form of a brief telephone interview.

Would you be willing to be contacted at a later data and answer some questions regarding edge deterioration and transverse profile measurement?

Appendix C. PowerPoint slides giving Feedback from Review Exercise

TTS on Local Roads:
Results of Consultation with Experts

S G McRobbie & M A Wright

Review of survey methods

Stage 1: Consultation and Review

Stage 2: Data Assessment

Stage 3: Reporting

Stage 1: Consultation and Review

- Results of the review shall be analysed to determine … information considered to be of particular interest in the maintenance and assessment of pavement condition.
- a basis for the initial requirements for TTS (05/06) may be determined
- "Brief but comprehensive"

Form of Review

Consultation with selected key experts overseas and in UK

Get information on:

- Types of surveys carried out
- Road types surveyed
- Practical difficulties
- Areas where successes or otherwise have been experienced

Overseas Review - Methodology

- TRL has extensive contacts in European and worldwide working groups in field of pavement condition assessment
- Selected key experts from organisations known to be interested in this subject
- Included equipment developers, operators and data users

Key points from Overseas Review

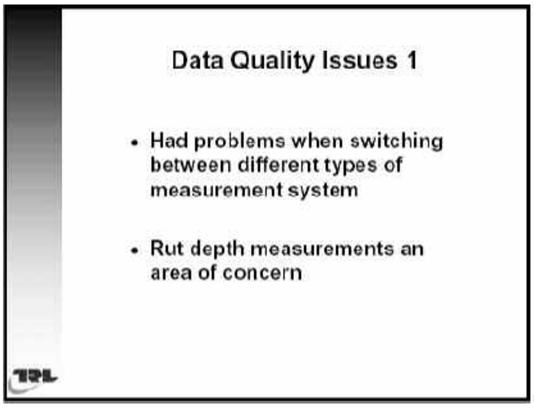
- Measured Parameters
- Key Concern Area – Edges
- Data Quality Issues
- Other Issues

Measured Parameters

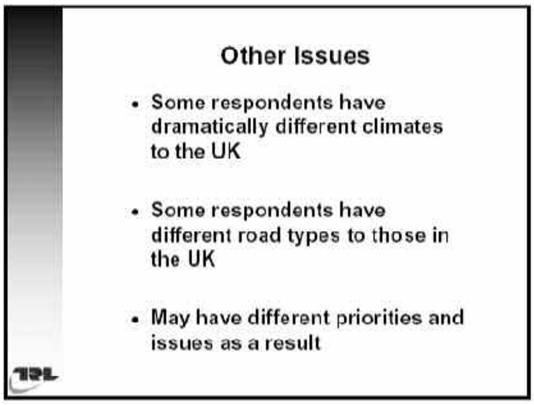
- Longitudinal profile, transverse profile/rutting, measured by all respondents
- Cracking not routinely measured
- Crack measurement or detection currently a hot topic for development

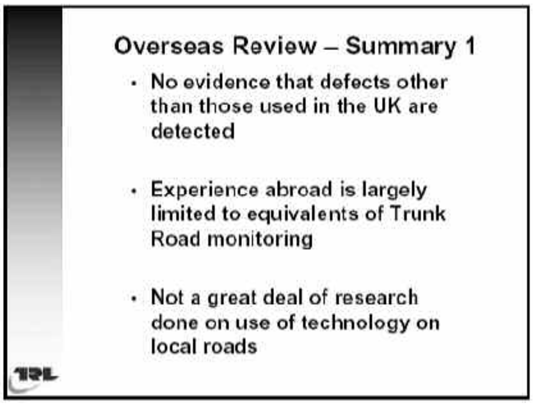
Key Concern Area - Edges

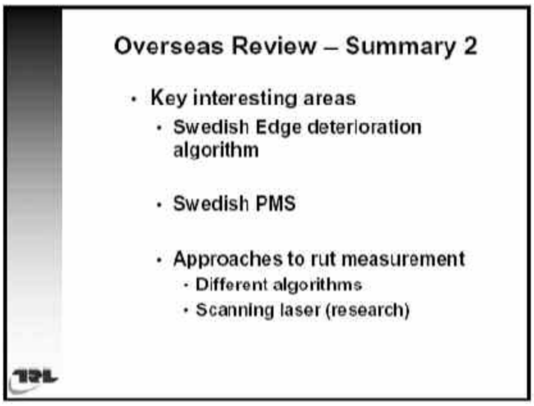
- Edge deterioration often mentioned as an area of concern
- Swedish have developed an Edge Deformation Index which aims to give indication of this
- Awaiting details of this

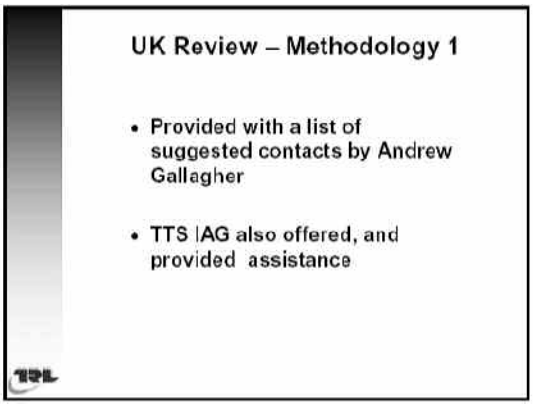

Data Quality Issues 1
• Had problems when switching between different types of measurement system
• Rut depth measurements an area of concern
TRL

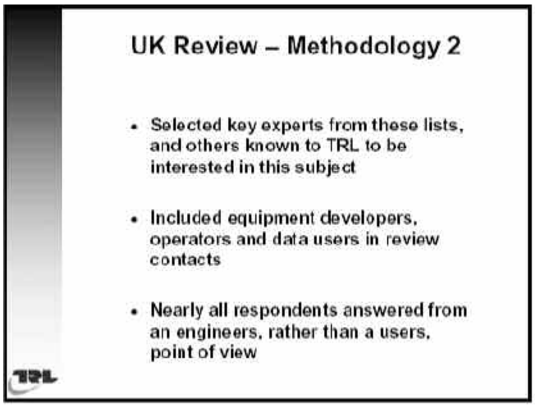

Data Quality Issues 2
• Some respondents perform quality assurance procedure during survey
• Claim that this improves quality of results
• Idea of vehicle, driver and operator accreditation
TRL


Other Issues
• Some respondents have dramatically different climates to the UK
• Some respondents have different road types to those in the UK
• May have different priorities and issues as a result
TRL


Overseas Review – Summary 1
• No evidence that defects other than those used in the UK are detected
• Experience abroad is largely limited to equivalents of Trunk Road monitoring
• Not a great deal of research done on use of technology on local roads
TRL


Overseas Review – Summary 2
• Key interesting areas
• Swedish Edge deterioration algorithm
• Swedish PMS
• Approaches to rut measurement
• Different algorithms
• Scanning laser (research)
TRL


UK Review – Methodology 1
• Provided with a list of suggested contacts by Andrew Gallagher
• TTS IAG also offered, and provided assistance
TRL


UK Review – Methodology 2
• Selected key experts from these lists, and others known to TRL to be interested in this subject
• Included equipment developers, operators and data users in review contacts
• Nearly all respondents answered from an engineers, rather than a users, point of view
TRL


Key Points from UK Review
• Experience and Attitudes
• Doubts and Concerns
• Visual Surveys
• Defects
• Rutting
• Longitudinal Profile
• Defect / Road type relationship
• Data Presentation / Handling
• Other Issues
TRL

Experience and Attitudes

- Almost all respondents had experience with TTS
- None had any objections to the principle of TTS, although some expressed that it would not be suitable in its current state
- Major perceived advantage was the objective nature of TTS surveys

Doubts / Concerns 1

- Lack of footway survey when using TTS
- Crack detection must improve – presently a "hit and miss affair"
- TTS can not yet distinguish different types of cracking – CVI can do this

Doubts / Concerns 2

- Many urban roads have traffic calming measures – issues with survey practicalities
- Whole concept of TTS on estate roads questioned
- Not enough vehicles

Visual Surveys 1

- Most important defects currently assessed in visual surveys were:
  - Rutting (structural / surface), cracking, edge deterioration, surface deterioration

Visual Surveys 2

- Other defects currently assessed in visual surveys and mentioned as important were:
  - Settlement / subsidence, components of surface deterioration (minor fretting, polishing, fatting up), distinction between wheeltrack and non - wheeltrack cracking

Rutting

- No evidence from review that rutting is seen as less important on minor roads
- No evidence that rutting may not be the most appropriate measure for assessing transverse condition of road, despite prior thoughts
- Only mooted as possibility by existing TTS users/suppliers

Longitudinal Profile 1

- No respondent not already using TTS mentioned longitudinal profile as an essential parameter to assess
- Issue of ride quality was mentioned, and was seen as of special concern in urban areas
- Survey vehicle performance in urban areas known to be sub-optimal

Longitudinal Profile 2

- Settlement and Subsidence was mentioned as a desirable defect to detect
- Possibly related to longitudinal profile

Longitudinal Profile 3

- Preliminary data analysis suggests longitudinal profile is affecting more of the network than rutting – particularly on B roads
- All respondents mentioned rutting as an essential defect to detect and quantify

Defect / Road type relationship

- Rutting and cracking seen as important on major / highly trafficked roads
- Edge deterioration and wearing course information of more concern on minor roads
- May be a difference between 'concern' and 'present'

Data Presentation

- Traffic light based data handling system similar to that used in Scotland seen as a good idea as a broad brush approach, but more detail needed to help targeting of resources
- Why use only 3 categories? HA uses 4 on Trunk roads

Data Handling

- Important that attention is paid to the fact that different defects are of different significance on different road types and classes
- This is true of all surveys, not just TTS
- UKPMS must develop if necessary

Other Points 1

- Trafficking levels seen as more important in determining survey and maintenance needs than designated road class
- Some respondents wanted TTS to effectively replicate CVI
- Some respondents thought there was no need or sense in trying to achieve this

Other Points 2

- Other information mentioned as being of interest included:
  - Surface type
  - Noise due to tyre/surface interaction
  - Condition of line markings
  - GPR data

UK Review – Summary 1

- Essential defects :
  - Rutting, cracking, edge deterioration, surface deterioration

UK Review – Summary 2

- Desirable defects:
  - Settlement / subsidence, components of surface deterioration, distinction between wheeltrack and non - wheeltrack cracking
  - Ability to distinguish surface and structural rutting

UK Review – Summary 3

- Practical issues with performing TTS on urban residential roads would make achievable daily survey lengths very small
- Issues involve:
  - On street parking
  - Traffic congestion
  - Manoeuvring in estates
- Need more accredited survey vehicles to cover whole non PRN

Consultation Exercise - Overall Results

- It seems unfeasible to include unclassified roads in this initial phase due to practical issues with performing surveys
- Must detect rutting, cracking, fretting and edge deterioration as minimum if surveys are to be accepted
- Next stage of consultation work must consider how longitudinal profile can be used to aid maintenance and monitoring of roads
- accreditation

Consultation Exercise - Recommendations

- Perform TTS to cover x% of B roads, and y% of C roads starting in April 2005
- These surveys must detect rutting, cracking, fretting and edge deterioration at least
- More survey vehicles must be available

Consultation Exercise – Research Requirements

- Edge Deterioration
- Crack Detection
- Rutting
- Longitudinal Unevenness
- Other Visual Defects
- Skid Resistance

Research requirements – Edge Deterioration

- Edge deterioration research must progress
- Work must be done in short term to develop a 'quick fix' method for detecting edge deterioration by 05/06
- This may simply detect presence of edge deterioration, but give no details
- Current work at TRL and in Sweden must be investigated and expanded where necessary to detect this important defect on local roads

Research requirements – Crack Detection

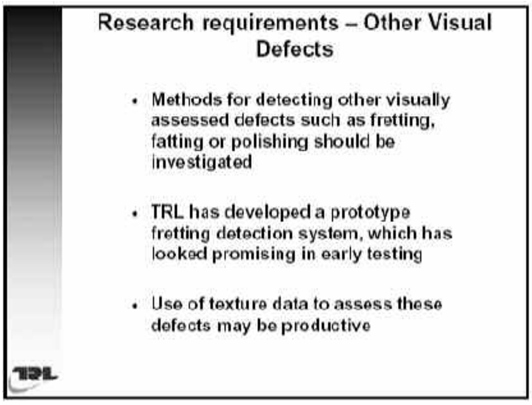
- Crack detection system must be developed and enhanced to distinguish different crack types if current UKPMS weightings and methods are to remain
- Accuracy of crack detection system must improve from its current 'hit and miss' state
- Ability to distinguish joints from cracks on concrete roads would be useful

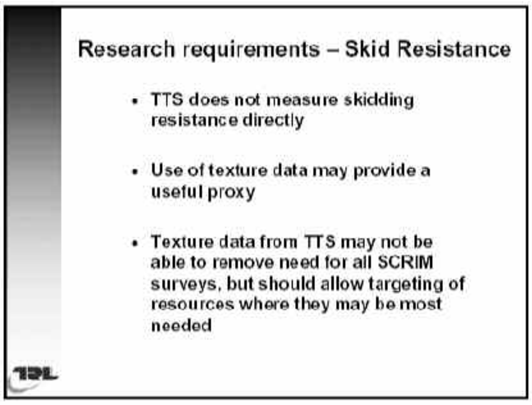
Research requirements - Rutting

- Work must be performed to assess limitations of using rut depths on local roads
- Different methods of calculating rut depths
- Use of other metrics for assessing transverse profile e.g. water ponding

Research requirements – Longitudinal Unevenness

- The way in which longitudinal profile or unevenness can be used to inform maintenance decisions must be investigated
- Investigation of calculation of longitudinal profile in more than one wheeltrack
- Results from SRMCS suggest there may be link between longitudinal unevenness and pavement condition on some road types


Research requirements – Other Visual Defects
• Methods for detecting other visually assessed defects such as fretting, fatting or polishing should be investigated
• TRL has developed a prototype fretting detection system, which has looked promising in early testing
• Use of texture data to assess these defects may be productive
TRL


Research requirements – Skid Resistance
• TTS does not measure skidding resistance directly
• Use of texture data may provide a useful proxy
• Texture data from TTS may not be able to remove need for all SCRIM surveys, but should allow targeting of resources where they may be most needed
TRL