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Developing SCANNER Road Condition Indicator parameter thresholds and weightings

Version 1

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Executive Summary

Project Title: Developing SCANNER Road Condition Indicator parameter thresholds and weightings

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This report presents the results of an assessment of the SCANNER Road Condition Indicator (RCI) carried out by TRL, and comprises the intermediate stage in the approach recommended by the Scoping study (Ekins and Hawker, 2003).

Investigations have been carried out to assess the behaviour of the SCANNER RCI. These have incorporated assessment and comparison with engineer's opinions at the site level, and investigation at the network level using a data set covering over 9000km of the local road network. These assessments have shown that the methodology employed in the SCANNER RCI to assess pavement condition is generally sound, but there is a need to modify a number of the thresholds and weightings used.

As a result of this work, a revised set of weightings and thresholds have been proposed. These revisions to the RCI result in the maximum possible score for any subsection reducing from 370 to 315 on A or B roads, from 370 to 290 for rural C or U class roads, and from 370 to 270 on urban C or U class roads.

The effect of the new thresholds and weighting on the RCI values reported on the network sample has been demonstrated. It was found that when moving from the current to the revised RCI settings the amount of Red reported (with an RCI value of 100 or above) decreases on all road classes. This decrease is largest on B roads, where more than half of the roads which were Red are now no longer Red.

Work has been carried out to investigate the behaviour of a number of new parameters, not available when the RCI was initially developed. This has enabled suitable thresholds and weightings to be proposed for the new measures of transverse unevenness (ADFD) and edge condition. It is proposed that an "Extended RCI" be calculated, by incorporating transverse unevenness within a family group with rutting, and by incorporating an entirely new Edge Condition Indicator (ECI).

The Extended RCI has been compared with the existing RCI by comparing the proportions of Red, Amber (RCI values of 20 up to 100) and Green (RCI up to 20) in the test dataset. It has been shown that the Extended RCI reports a larger proportion of Red lengths due to the introduction of the ADFD and ECI values. The new parameters have very little effect on the A roads, as would be expected, but more of an effect on the other classes, particularly on the minor classes, and particularly on rural roads.

Work has been carried out to assess the sensitivity and confidence of the RCI results to the proportion of the network surveyed, in order to derive recommendations for the proportion of the network to survey. From this work, minimum survey lengths are recommended for networks of different lengths, to obtain 95% confidence that the reported percentage Red lies within ±0.75 of the true value.

An investigation was also carried out to identify characteristics of local authorities that would enable them to be placed in groups of comparable performance, so that benchmark values could be established. However, while there is considerable variation in the percentage of Red roads, it proved impossible to define satisfactory groups to differentiate between different types of local authority.

A simple trajectory tool has been developed to assist local authorities in exploring the possible consequences of different maintenance scenarios on the condition of their network. This consists of a Microsoft Excel spreadsheet that imports the initial condition of the network and applies simple assumptions about the effects of deterioration and maintenance, to explore how the network condition evolves over a period of 5 years.

A number of areas for further research have been highlighted as a result of this work. These include revisiting the RCI in 12 months when additional data and experience have been obtained, incorporating more parameters which have been added to SCANNNER surveys, conducting training workshops to familiarise the end users with the use and limitations of the RCI, and further development of the projection and maintenance algorithms that underpin the trajectory tool.

In addition, the RCI (and extended RCI) provide a single measure of condition, whereas engineers have to consider a range of needs when maintaining their networks, including safety, structural and user needs. The RCI approach could deliver further indicators to report performance in these areas, which could help plan maintenance to meet a diverse range of needs. It is recommended that further work be carried out to consider the potential of such additional indicators.

1 Introduction

This report presents the results of the assessments carried out by TRL of the SCANNER Road Condition Indicator (RCI).

SCANNER surveys have been developed on behalf of the DfT to provide an objective, consistent approach for assessing the condition of all non-Principal roads across the country. Such surveys use accredited vehicles to perform automated surveys conforming to specifications defined by the DfT.

It was recognised from an early stage in the SCANNER development (or *TTS on Local Roads*, as it was then known) that some form of Condition Indicator would be required for use with the data (Ekins and Hawker, 2003, referred to this as a Defects Index). The scoping study recommended a three stage approach to the development of this indicator to allow the surveys to be introduced as quickly as practical, initially basing them heavily on what was done on Highways Agency roads; then refined following experience and research; then finalised once the survey technology had had time to adapt to the new non-Principal road environment. It was recommended that the indicator to use with SCANNER data should also go through a staged process of development, an initial analysis, an interim analysis, and a final analysis. This report deals with the intermediate stage in the approach recommended by Ekins and Hawker.

The work set out to investigate the behaviour of the RCI as currently implemented, and to investigate the suitability of the current thresholds and weightings on B, C and unclassified rural and urban roads. The work also investigated some uses for the RCI results, and the ways in which a local authority might use its RCI data to plan its future maintenance programme, or funding requirements. Finally, a number of new parameters have been developed for delivery in SCANNER surveys. The suitability of these parameters for inclusion within the RCI, and the optimum means of including them were investigated.

The report is separated into 7 Sections following this introduction:

- Section 2 describes the data sources used in the investigation;
- Section 3 describes work carried out to investigate the behaviour of the RCI. This had the objective of determining how the RCI reports the condition of the network and how this reflects the expected behaviour and the opinions of engineers. This has enabled proposals to be made regarding changes to the calculation of the RCI on each road class;
- Section 4 discusses the effect, on BV224a, of varying the amount of C roads included in the calculation;
- Section 5 investigates establishing benchmark values to allow performance comparisons;
- Section 6 presents the results of work carried out to develop methods to determine the evolution of network RCI values over time, to assist engineers in determining the likely effect of deterioration and maintenance on the RCI reported for their network;
- Section 7 discusses the integration of the new parameters (such as Edge Deterioration and Transverse Unevenness) into the RCI;
- Section 8 summarises the findings and discusses the implications for SCANNER.

2 Data sources

To undertake the investigation of the SCANNER RCI a database was established containing data provided by the SCANNER survey contractors. The data was provided as SCANNER HMDIF files from each of the three survey contractors for a total of 16 local authorities from the 2005/6 survey. The authorities were chosen on the basis of their potential to cover a range of road conditions, road types, and authority types. Additionally the representative nature of the data set was assessed statistically to establish its suitability for use in this work, as described below in Section 2.1. Table 1 shows a summary of the data sources used in the research.

The following observations should be noted for the dataset:

- 10m subsections which did not contain valid data for all parameters were excluded from the analysis.
- A number of 10m subsections were removed from the analysis because it was not possible to process the HMDIF files containing these sub-sections through TRL's processing software.
- The measurement of cracking by DCL is undergoing further development as part of the SCANNER accreditation process. It has been recognised that the 2005/6 DCL survey data is not consistent with the other survey contractors, as a result of the measurement of cracking. Data provided by DCL was therefore removed from any assessment of the RCI and parameter distributions where cracking could have an affect on the analysis.
- Only WDM were able to provide data for the new SCANNER parameters developed in the SCANNER research programme (e.g. edge deterioration).

Following the exclusions mentioned above, the remaining dataset used in the research was a total of 9325km in length (8670km excluding DCL), and comprised the data detailed in Table 1.

Authority	SCANNER Contractor	Length (km)
Bracknell	Jacobs	132
Co. Durham	Jacobs	810
Doncaster	Jacobs	242
Kent	Jacobs	1527
Leeds	Jacobs	420
Portsmouth	Jacobs	82
	Jacobs total	**3213**
Bexley	WDM	146
Cambridgeshire	WDM	1215
Harrow	WDM	97
Leicestershire	WDM	238
Lincolnshire	WDM	2108
Perth and Kinross	WDM	346
Surrey	WDM	1163
Torbay	WDM	144
	WDM total	**5457**
Birmingham	DCL	323
Herefordshire	DCL	332
	DCL total	**655**
Total		**9325**

Table 1: Data used in research

2.1 Establishing the representative nature of TRL sample dataset

As stated above, work was carried out to assess the data sources to ensure that they were representative of the local road network. This assessment was undertaken by comparing the RCIs of the selected local authorities (LAs) with the RCIs reported over the English UK local road network. To assess how representative the TRL sample data sources were of the overall population of LAs', Chi-squared tests were computed for each of a set of key variables.

The probability value (*p-value*) obtained indicates whether the distribution of the sample is similar to the complete population for the particular variable under consideration. Given a null-hypothesis that the TRL sample is representative of the whole population of LAs, a p-value less than 0.05 indicates that, at the 5% level or better, there is a significant difference between the distributions of the sample and of the whole population for the for the particular variable under consideration.

The following variables were tested:

- Percentage of RCI coded red for all roads
- Percentage of RCI coded red for A roads
- Percentage of RCI coded red for B roads
- LA Region
- Percentage of built-up roads
- Length LA of network
- Percentage of A roads

Note that, in order to test these scalar variables, some grouping was required. To minimise the effect of the grouping on the test results a consistent method of grouping was followed for each variable. Tests were also carried out to determine the sensitivities of the groups and, in particular, whether changing the group definitions affected the conclusion about that variable.

The results of the statistical tests on the sample data set are shown in Table 2 to Table 8. It can be seen that, of the variables tested, most suggest that the sample dataset is not significantly different from the overall population. However, two variables do show significant differences between the distribution of the sample and the overall population, these are the percentage of red RCI values for B roads ($p < 0.05$) and total length of network ($p < 0.01$). These are highlighted in red in the tables, with their respective p-values. The test for the length of network variable highlights the group "> 2000" as being over-represented in the sample dataset. This observation was considered against the need for continuing progress on the project, and the likely significance of the areas in which the dataset was found to be unrepresentative. The options were: to change the sample in order to adjust for this mismatch or, given that virtually all the other variables tested were not significantly unrepresentative of the population, to keep the sample the same. It was acknowledged that 16 LAs was a small dataset, and that the creation of a significantly larger test dataset would be outside the scope of the project. It was felt that it would be difficult to establish a small sample that was significantly more representative for all variables. Therefore the decision was made to proceed with the research using this dataset.

Overall percentage of red RCI values	Population	Sample
<= 10%	43	8
10% – 20%	57	5
> 20%	47	3
Sum	147	16
p-value	> 0.05 i.e. not significant	

Table 2: Significance of overall percentage of Red

Percentage of red RCI values for A roads	Population	Sample
<= 10% 10% – 20% > 20%	51 61 37	3 8 5
sum	149	16
p-value	> 0.05, not significant	

Table 3: Significance of percentage of Red on A roads only

Percentage of red RCI values for B roads	Population	Sample
<= 10% > 10%	73 77	12 4
Sum	150	16
p-value	< 0.05, significant at 5%	

Table 4: Significance of percentage of Red on B roads only

Region	Population	Sample
North Central South	49 67 33	4 8 4
sum	149	16
p-value	> 0.05, not significant	

Table 5: Significance of region

Percentage of built-up roads	Population	Sample
<= 75% 75% - 95% > 95%	52 32 65	9 2 5
sum	149	16
p-value	> 0.05, not significant	

Table 6: Significance of built-up percentage

Length of network (km)	Population	Sample
<=500 500-2000 >2000	36 75 38	3 3 10
sum	149	16
p-value	< 0.01, significant at 1%	

Table 7: Significance of network length

Percentage of A roads	Population	Sample
<= 8% 8% - 10% > 10%	53 60 36	4 8 4
sum	149	16
p-value	> 0.05, not significant	

Table 8: Significance of proportion of A roads in network

3 The behaviour of the RCI

In this section we shall discuss the behaviour of the current RCI (2005/6 and 2006/7 specification) and present the results of observations made concerning the contribution of the individual parameters that make up the RCI on the resulting RCI value.

In particular, this section asks a number of questions regarding the success of the RCI in relation to its reporting of the condition of the network against the opinions of engineers, and the extent to which the reported value of the RCI represents the condition we may expect the network to have. These questions and observations then allow us to ask whether there is justification to modify the RCI, what these modifications may be, and what benefits would result from these changes.

3.1 Methodology

The investigation of the behaviour of the RCI, and the effect of any potential modification, was carried out using two approaches: a theoretical study, and a workshop.

Theoretical study

The theoretical studies concentrated on assessing the trends observed in the individual parameters and the RCI data contained within the dataset of 16 Local Authorities described in the preceding section. The data was examined to identify any areas where the RCI was performing anomalously, or where there was room for improvement or simplification of the RCI model. Frequent use is made of plots of the distributions of data values on various networks (e.g. Figure 2, Figure 28, Figure 32), to support arguments for, or against, modification. These distributions show how the values of individual parameters are distributed over the network, when reported within bins of a certain size. Note that, traditionally, such plots are displayed as bar charts, but it was found that this representation did not simplify interpretation.

Note that, when assessing the distributions of the cracking parameters used in the calculation of the RCI, it was necessary to remove the DCL data from the dataset. Table 9 shows the total lengths of data used for each parameter.

Parameter	Rutting	Texture	3m LPV	10m LPV	Carriageway cracking	WT cracking	RCI
DCL data included	Yes	Yes	Yes	Yes	No	No	No
Length (km)	9325	9325	9325	9325	8670	8670	8670

Table 9: Data used in calculation of individual parameter value distributions

Workshop

A workshop was held with experienced engineers to review the RCI, and hence obtain opinions regarding the behaviour of the RCI against engineer's expectations. The workshop was held at TRL, using a set of six sites located on the local road network as the basis for discussion. Details of the workshop participants, the sites visited, and a summary of the opinions obtained, are given in Appendix A.

In selecting the sites the objective was to identify very poor sites, a site in good condition, and a number of sites rated as upper Amber to low Red. Ideally the sites selected would have scored points due to the presence of a single defect, or specific combination of defects. Short listed sites were visited by a member of the project team, accompanied by an experienced engineer from Bracknell Forest Borough Council, to assess their suitability, access and safety for use in the workshops. The

Six sites selected are shown in Figure 1. Table 10 summarises the sites, including the justification (based on examination of SCANNER HMDIF data) for initial selection.

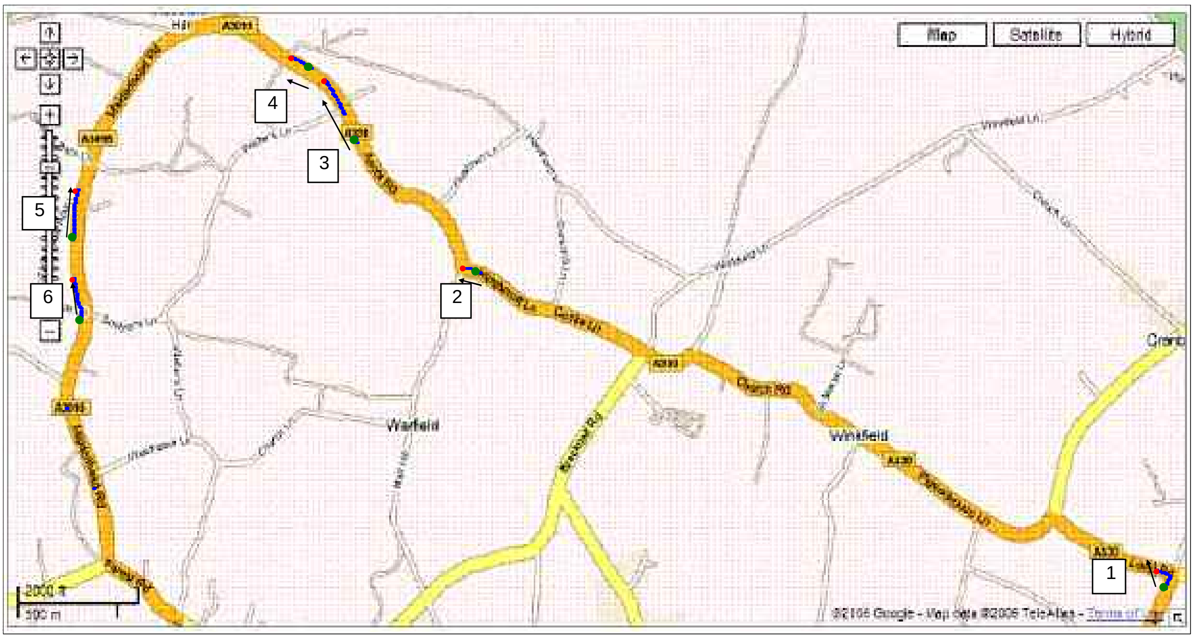


Figure 1: Map showing location of workshop sites located on A3095 and A330 north of Bracknell

Workshop Site ID		Section	Reason for selection	SCANNER Average RCI
6	start end	A3095/325 A3095/325	high RCI	176.88
5	start end	A3095/325 A3095/330	texture rut	96.64
1	start end	A330/210 A330/290	high RCI	200.47
2	start end	A330/330 A330/330	low RCI	8.85
3	start end	A330/340 A330/345	LPV crack	114.88
4	start end	A330/345 A330/345	crack	68.53

Table 10: Details of sites selected for use in TRL RCI Workshop

**Site 1 was later split into sites 1a and 1b as the geometry of the site (round a corner) and site condition were such that this was deemed more appropriate by the attendees of the Workshop*

During the workshop attendees were firstly given a brief introduction to SCANNER, and the RCI, and site visits were then carried out by the workshop participants. At each site participants were asked to make notes regarding the condition of the site, and record their opinions on the need for maintenance. Participants were also asked to give each site an RCI score, based on their assessment of the condition. Note that, during the site visits, the participants were asked to consider all sites as if they were subject to the same levels of traffic, and were equally important to the local hierarchy.

After the site visits were complete a group discussion was held during which the engineers explained why they had rated each site as they had, and differences between the opinions of different engineers were discussed. The RCI of each site reported by the SCANNER survey was then revealed, and the participants were asked whether or not they felt these were acceptable or understandable.

3.2 RCI behaviour

Throughout this section the discussion of the behaviour of the RCI is presented on the basis of six key questions, which are used to support any changes to the RCI:

- Observation – what general observation has been made about the RCI/parameter, or has become apparent as a result of the investigations carried in this work?
- Evidence – what is the evidence that lead to the above observation?
- Action – what action should be taken (if any) to improve matters?
- Test – what test should be carried out to test the appropriateness of the above action?
- Result – what is the result of the test?
- Recommendation – what is the recommended change (if any)? What are the benefits of this?

In general, the proposed actions resulting from each observation have been tested in isolation from other proposed actions. This means that when testing the effect of changing the manner in which the RCI deals with cracking data, the recommendations for changes to the way in which LPV data are dealt with are not implemented.

3.2.1 Provenance of initial RCI thresholds and weightings

Many of the thresholds used in the initial version of the RCI were derived from existing values defined within Highways Agency advice. The Highways Agency thresholds themselves had been developed within the Agency's research programme, including studies of user perception and establishing relationships with safety and risk. However, because the Highways Agency thresholds were developed for Trunk Roads, when developing the RCI for lower classes of road it was necessary to modify these thresholds. This modification was based on experience (in terms of the levels that were being observed in routine surveys) and judgement. These modifications were proposed in the initial development of the RCI carried out by Chris Britton Consultants (CBC), and during development of an indicator for Scotland, for the SRMCS.

3.2.1.1 LPV

The LPV thresholds are largely based on those proposed in the Highways Agency document Interim Advice Note (IAN) 42/05. These were set following user perception studies to gauge the acceptable levels of ride quality on Highways Agency roads. Table 11 and Table 12 show the threshold levels used in the initial RCI model. Note that the approach applied in the RCI differs from that applied on trunk roads in that the rural LPV thresholds are greater than the urban ones. This is based on the approach of the SRMCS, which assumes that users do not expect a smooth ride when on minor roads, in rural areas.

3m	T_L	T_U	Source	Weighting
A	4	10	IAN 42/05 Urban Dual – also BV96 used $4mm^2$	80
B	4	10	IAN 42/05 Urban Dual– also BV96 used $4mm^2$	80
C/U urban	7	17	IAN 42/05 Urban Single	80
C/U rural	15	25	SRMCS, CBC	80

Table 11: Existing thresholds and weightings used in RCI calculation with 3mLPV data

10m	T_L	T_U	Source	Weighting
A	21	56	IAN 42/05 Urban Dual	60
B	21	56	IAN 42/05 Urban Dual	60
C/U urban	45	90	IAN 42/05 Urban Single	60
C/U rural	45	130	Unknown	60

Table 12: Existing thresholds and weightings used in RCI calculation with 10mLPV data

3.2.1.2 Cracking

The Highways Agency does not use cracking in its indicator, and recommends thresholds for guidance only. The values selected for use as TL (0.15%) are found in IAN 42/05, but the value for TU (0.5%), which was in IAN 42/02 has been removed from IAN 42/05.

Table 13 shows the values used for TL and TU for whole carriageway cracking in the existing RCI model. Neither the Highways Agency nor the SRMCS specify thresholds for wheeltrack cracking, as very little research has been done in this area. It is assumed that the thresholds selected for use in the RCI model were developed from consideration of the ranges of values observed on the network. Table 14 shows the values selected.

Carriageway	T_L	T_U	Source	Weighting
A	0.15	2	T_L from IAN 42/05; T_U from IAN 42/02	50
B	0.15	2	T_L from IAN 42/05; T_U from IAN 42/02	50
C/U urban	0.15	2	T_L from IAN 42/05; T_U from IAN 42/02	50
C/U rural	0.15	2	T_L from IAN 42/05; T_U from IAN 42/02	50

Table 13: Existing thresholds and weightings used in RCI calculation with carriageway cracking data

Wheeltrack	T_L	T_U	Source	Weighting
A	0.5	5	Unknown – CBC report	40
B	0.5	5	Unknown – CBC report	40
C/U urban	0.5	5	Unknown – CBC report	40
C/U rural	0.5	5	Unknown – CBC report	40

Table 14: Existing thresholds and weightings used in RCI calculation with wheeltrack cracking data

3.2.1.3 Rutting

The Highways Agency IAN documents, the SRMCS, and Kent all use a lower threshold of 11mm, and an upper threshold of 20mm. Table 15 shows the values used in the initial RCI model. It can be seen that the thresholds for rutting on C and U roads have been set at higher levels in the RCI. The source of this raising of the thresholds is unknown, but it is assumed that these have been set at this level to reflect the lower significance of rutting on these road types.

Rutting	**T_L**	**T_U**	**Source**	**Weighting**
A	10	20	T_L very close to value of 11 used in IAN 42/05; T_U from IAN 42/05	90
B	10	20	T_L very close to value of 11 used in IAN 42/05; T_U from IAN 42/05	90
C/U urban	12	25	Unknown – CBC report	90
C/U rural	15	30	Unknown – CBC report	90

Table 15: Existing thresholds and weightings used in RCI calculation with rut data

3.2.1.4 Texture

IAN 42/05 gives texture threshold values of 0.8mm and 0.4mm for use on all non HFS surfaces, and a single threshold of 0.6mm for use on HFS. These represent a change from those specified in IAN 42/02, which proposed 0.6mm and 0.3mm for use on concrete surfaces, and 1.1mm and 0.6mm for use on all non-concrete, non-HFS surfaces. The changes reflect the results of extensive research into the relationship between texture depth and high-speed skid resistance research carried out by the Agency. The RCI thresholds are the same as those used in the SRMCS, at 0.6mm and 0.3mm. Note that these were defined before the changes made to the Agency advice (i.e. before the further research). Table 16 shows the texture thresholds used in the initial RCI model.

Texture	**T_L**	**T_U**	**Source**	**Weighting**
A	0.6	0.3	SRMCS / IAN 42/02	50
B	0.6	0.3	SRMCS / IAN 42/02	50
C/U urban	0.6	0.3	SRMCS / IAN 42/02	50
C/U rural	0.6	0.3	SRMCS / IAN 42/02	50

Table 16: Existing thresholds and weightings used in RCI calculation with texture data

3.2.2 General Behaviour

<u>Observation:</u>

The overall distribution of RCI values seems intuitively right, given the nature of the indicator and the way in which it has been implemented.

<u>Evidence:</u>

The distribution of RCI values in the TRL test dataset (over 9300km) can be seen in Figure 2 for A, B, C and U(nclassified) roads. The plot shows the Amber threshold at 20, and the Red threshold at 100 as dotted lines.

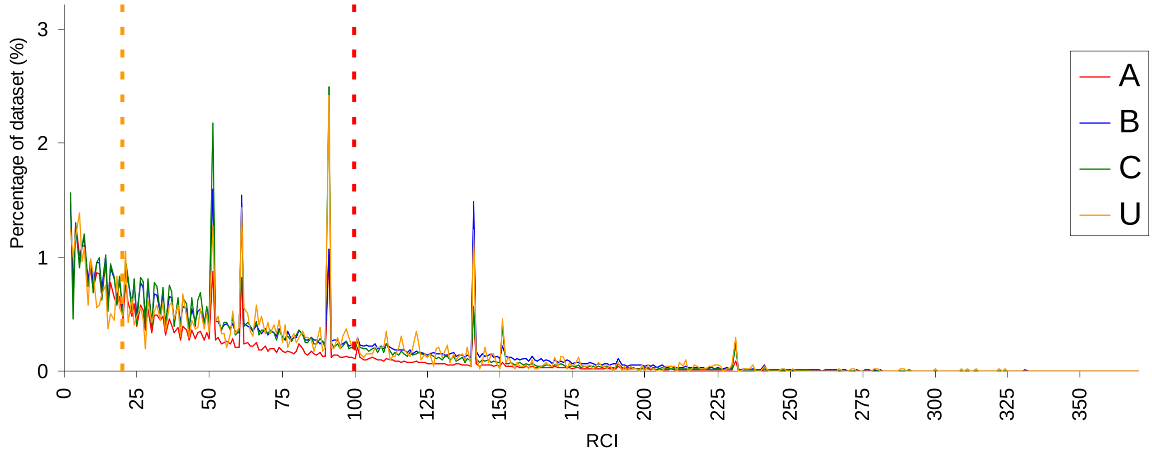


Figure 2: Distribution of RCI values for A, B, C and Unclassified roads

This plot excludes subsections with RCI values of zero, as these would otherwise overwhelm the graph and make interpretation very difficult. The proportions of the data for which RCI scores of zero are obtained are as follows:

- A roads - 52.35%
- B roads - 29.67%
- C roads - 32.52%
- U roads - 35.18%

Peaks can be seen in Figure 2 at a number of RCI values due to the nature of the RCI calculation and the maximisation of RCI contributions from certain defects:

50 - maximum RCI contribution due to texture;

60 - maximum RCI contribution due to 10m Longitudinal Profile Variance (LPV);

90 - maximum RCI contribution due to rutting, or both crack parameters;

140 - sum of 90 (rutting or both crack parameters) and 50 (texture);

150 - sum of 90 (rutting or both crack parameters) and 60 (10m LPV);

230 - sum of 90 (rutting) and 90 (both crack parameters) and 50 (texture).

In addition there is a smaller peak, most apparent on A roads, at 80. This is due to the contribution of maximum weighted scores of 3m LPV to the RCI, but where no other defect is present. Generally 3m LPV is reported in conjunction with at least some 10m LPV (as discussed further in Section 3.2.4), and so this is a very small peak.

Figure 3 shows the Red, Amber and Green percentages of the RCI values for each of the 16 Local Authorities included in the dataset. The two authorities which clearly stand out as different are those numbered 2 and 8. These were surveyed by DCL, and the difference in behaviour can be attributed to the inconsistencies of DCL's data.

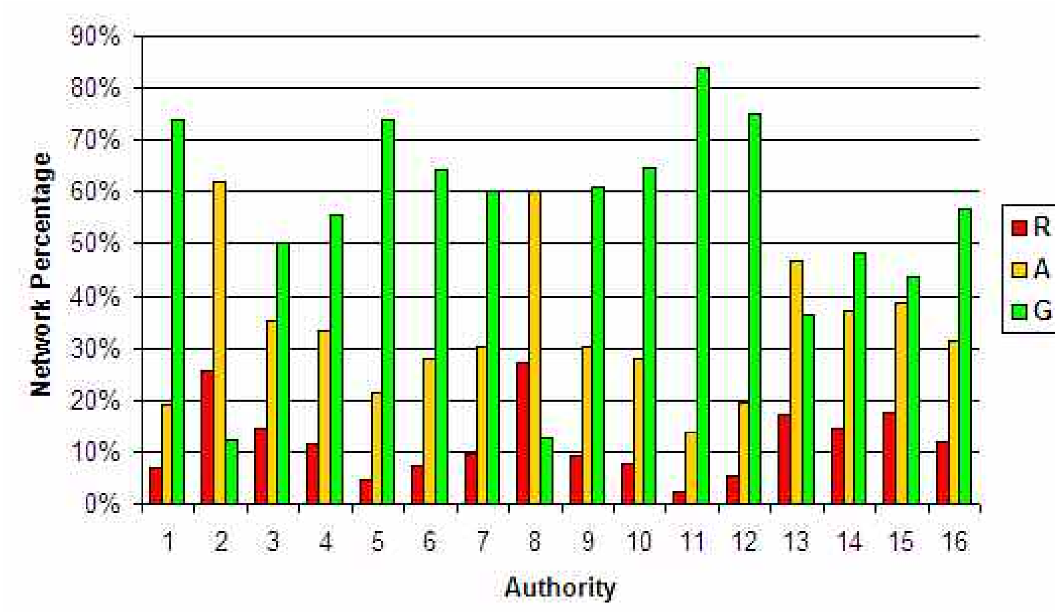


Figure 3: Red, Amber and Green proportions of the 16 Local Authorities calculated using the standard RCI model displayed individually for each LA.

Figure 4 shows the Red, Amber and Green proportions of the 16 LA dataset. As with the individual authorities, the heights of the red, amber and green columns indicate that more than half of the network is sound, about one third is in a condition which justifies further monitoring (and consideration for future maintenance), and a minority requires maintenance soon (the precise definitions of Red, Amber and Green are given in Appendix B). Therefore, examination of the plots appears to show that the RCI performs reasonably well at a network level, in terms of the proportion of the network that might be expected to be allocated to Red, Amber and Green, given the definitions of the categories.

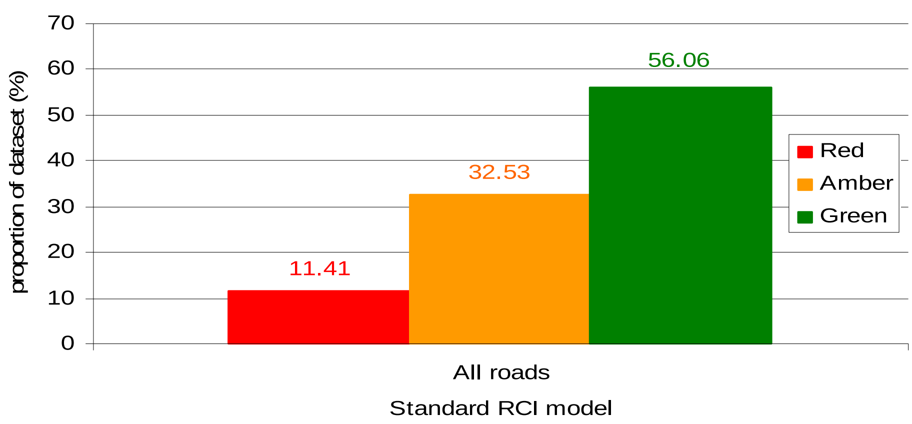


Figure 4: Red, Amber and Green proportions of the 16 Local Authorities calculated using the standard RCI model displayed as an overall dataset.

Beyond network level assessment, a further function of the RCI is to provide more site-specific information to assist in indicating the maintenance need of any individual site. This was investigated in the workshop. Table 17 shows the average RCI scores for each of the sites visited during the workshop as calculated by the existing RCI model (with and without manual cracking data).

Note that the RCIs of the workshop sites were initially obtained from the HMDIF files provided by the SCANNER survey contractors, which included the results of the automatic crack identification. Examination of this data showed that, in many locations, the cracking reported was not a good representation of the cracking actually present on the site. This introduced a further layer of complexity in the assessment of the RCI – that of the influence of poor cracking data. It was decided that the influence of poor cracking data would complicate the assessment of the workshop data and prevent its successful use in assessing the capabilities of the RCI. Therefore a manual analysis was undertaken of the HARRIS video images of the sites to obtain unambiguous cracking data, and this was substituted for the crack data provided in the HMDIF files. The resultant RCIs are referred to as "RCI with manual crack analysis" (see Table 17). The manual crack data has been used in all discussions of the use of RCI on the SCANNER workshop sites unless explicitly stated otherwise.

Workshop Site ID	Average engineer proposed RCI	SCANNER Average RCI	Average RCI with manual crack analysis
1(a)	127	215	190
1(b)	35	185	141
2	11	9	8
3	24	115	48
4	50	69	0
5	149	97	129
6	151	177	125

Table 17: RCI ratings of sites used in the workshop.

Table 17 shows the RCI proposed for each site by the engineers attending the workshop, and Figure 5 shows the relationships between these values and those calculated using the SCANNER survey data, both with and without use of manual crack data. It can be seen that there is some agreement between the SCANNER and engineer derived RCIs across the sites, with higher engineer RCIs corresponding to higher SCANNER RCIs, indicating that the SCANNER RCI assigns higher scores to sites which are of more concern to engineers. It can also be seen that the RCI calculated with the manual crack data generally provides better agreement with the engineer's assessments of the site condition. Further discussion of the use of crack data within the RCI is discussed in Sections 3.2.9 and 3.2.14.

It must be noted that the data as presented in plots such as Figure 5 are not, in isolation, strong evidence for any of the proposed changes. However, taken as a part of a larger body of evidence, and with expert judgement, such plots do provide some justification for the changes proposed, and are a visual way of conveying the effect of the different proposed models.

Although there is some agreement between the SCANNER RCI and the RCI proposed by engineers, there is undeniable scatter in the data. Examination of Table 17 and Figure 5 shows notable differences between the values for Site 1b and Site 4 (highlighted by blue ellipses). These were considered in further detail, and discussed with the engineers attending the workshop. It was noted that the SCANNER survey data from Site 1b contained significant levels of LPV, which were not easily observable in the walked visual survey carried out during the workshop. Furthermore, the engineers expressed the opinion, when presented with the LPV evidence from the SCANNER survey, that they would not have placed such importance on the LPV data. Discussion of Site 4 revealed that the engineers felt this site to be worthy of further monitoring. However, the manual cracking data from this site gave rise to a low rating for the RCI.

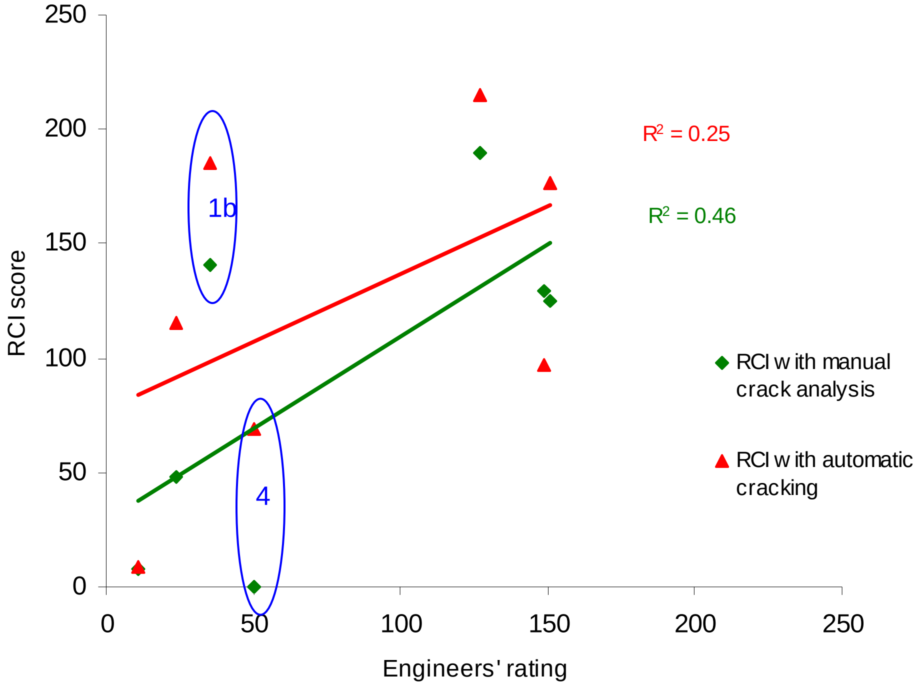


Figure 5: Relationships between average Engineers' site rating, and SCANNER RCI with automatically and manually derived crack data (Note: order of sites on horizontal axis is 2, 3, 1b, 4, 1a, 5, 6)

Proposed Action:

Initial assessments of the distribution of values delivered by the RCI show that the proportion of the network identified within each condition category is in reasonable agreement with that which may be expected. This would suggest that radical changes to the RCI are not appropriate. However, there are more subtle effects present which may justify adjustments to the calculation of the RCI. From this initial assessment it is apparent that these include:

- Investigating the influence of cracking;
- Investigating the influence of longitudinal profile variance (LPV).

Testing, results and recommendations:

The above areas for further development are discussed further in sections 3.2.4, 3.2.5, 3.2.6 and 3.2.7 (LPV), and 3.2.8 and 3.2.9 (cracking).

3.2.3 Contributions of individual parameters to the RCI

Observation:

Due to the threshold values selected for each parameter used in the RCI, the proportion of the network contributing a non-zero value to the RCI varies by parameter.

Evidence:

The upper plot in Figure 6 shows the contribution to the RCI value made by each parameter, over the range of parameter values observed (the range is shown as a percentile value of the all the values recorded), on all classes of road. The lower plot in Figure 6, shows the unweighted contributions to the RCI of the different parameters. It can be seen that the weighted parameters contribute different values to the RCI at similar percentiles. For example the 85th percentile value of carriageway cracking (0.54%) contributes a score of 11, whilst the 85th percentile value for the rutting (9.3mm) contributes nothing to the RCI.

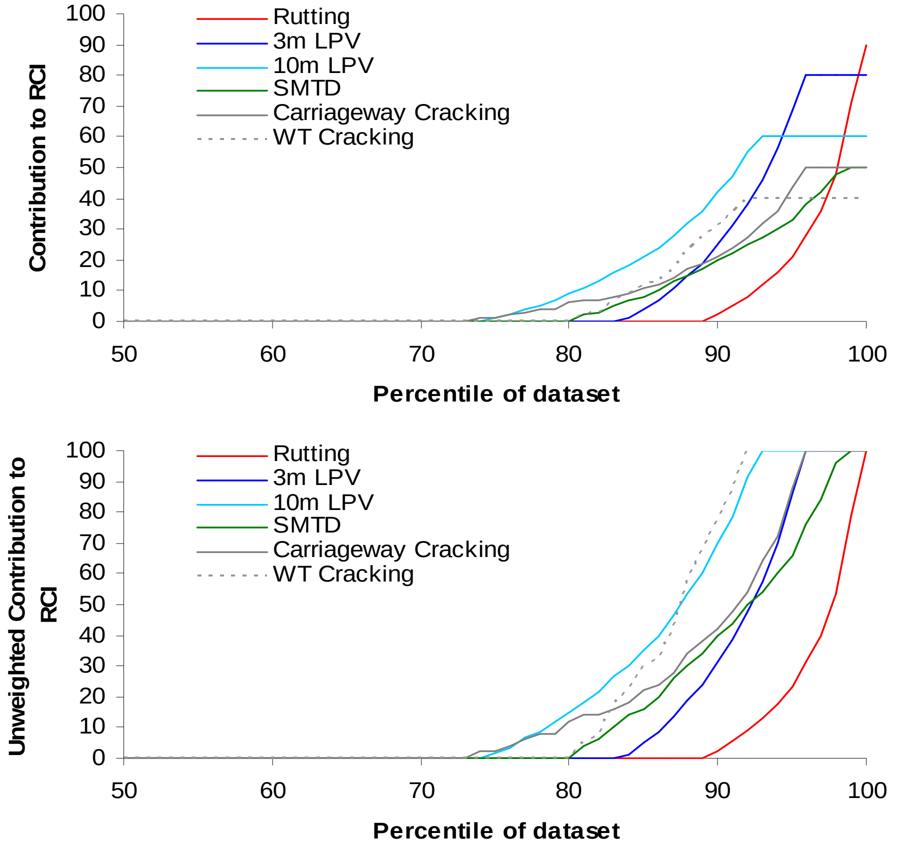


Figure 6: Contribution of each parameter to RCI at different parameter percentile values for all roads in TRL sample dataset. Top plot shows weighted contributions, as defined by Reliability and Importance. Bottom plot shows unweighted contributions.

Figure 7, Figure 8, Figure 9 and Figure 10 show the contribution of each parameter to the RCI for each class of road (A, B, C and U), and again presents the contributions as weighted and unweighted values. It is clear that not all the parameters contribute to the RCI over equal lengths of the network, and that some parameters contribute proportionately more to the RCI for one class of road than another.

Also apparent in Figure 6 to Figure 10 is the fact that the two cracking parameters, carriageway and wheeltrack cracking, tend to contribute non-zero scores toward the RCI over more of the network than any of the other defects. Furthermore, rutting is seen to affect very little of any of the networks, or the network as a whole, while texture is seen to have a greater influence on B, C and U roads, than on A roads. When this behaviour was discussed with engineers there was concern expressed that some defects were having a very different contribution to the reported RCI than others, which did not necessarily reflect their relative importance.

Although the use of RCI data as a method for predicting trends in the condition of a network has been investigated as part of this work (Section 6), this is not what the RCI was primarily designed for, and the RCI may not be the most appropriate tool for performing such predictions, depending on the levels of accuracy required.

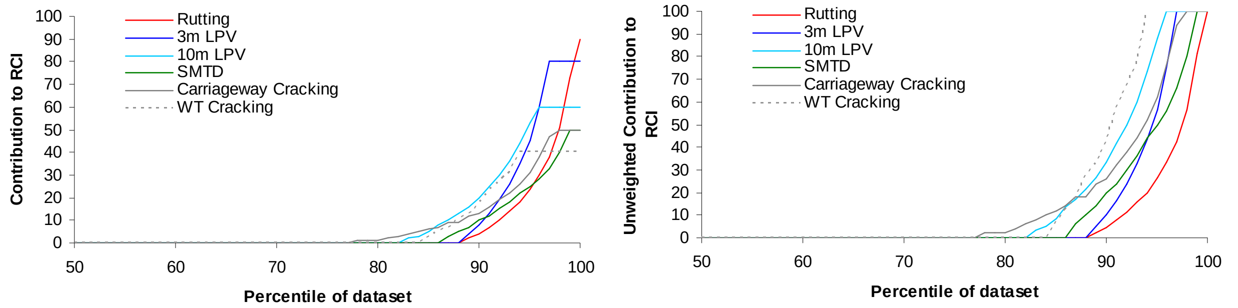


Figure 7: Contribution of each parameter to RCI, by percentile, for <u>A</u> roads in TRL sample dataset. Left plot shows weighted contributions, right plot shows unweighted contributions (with all parameters scoring 0 at T_L and 100 and T_U).

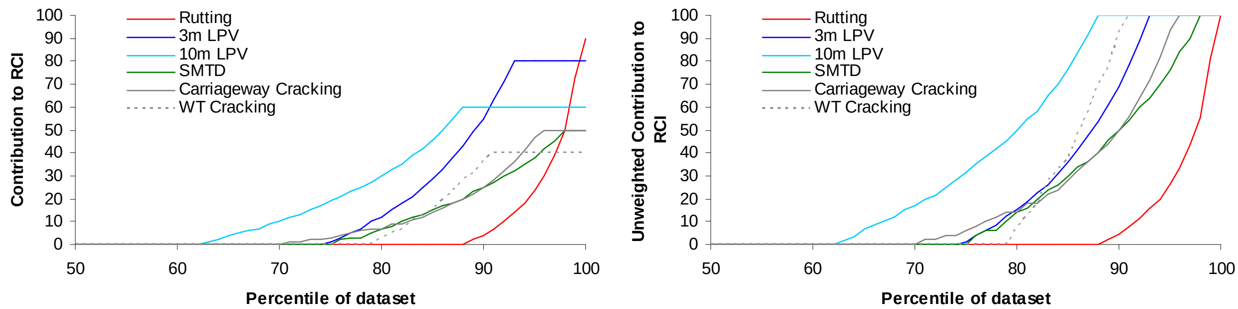


Figure 8: Contribution of each parameter to RCI, by percentile, for <u>B</u> roads in TRL sample dataset. Left plot shows weighted contributions, right plot shows unweighted contributions (with all parameters scoring 0 at T_L and 100 and T_U).

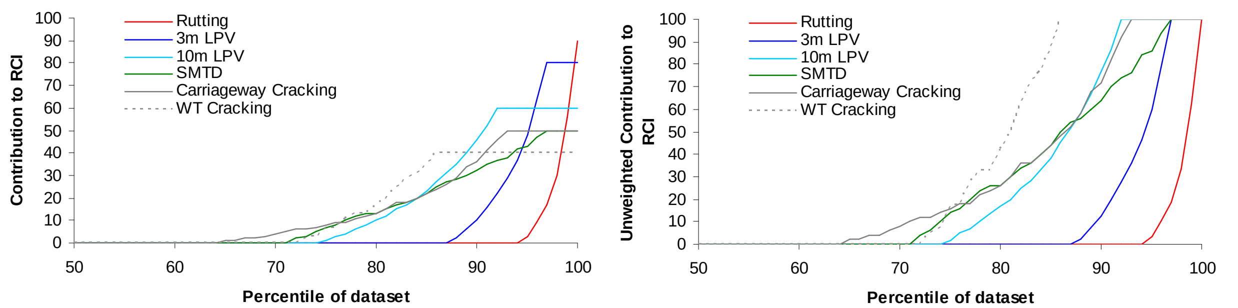


Figure 9: Contribution of each parameter to RCI, by percentile, for <u>C</u> roads in TRL sample dataset. Left plot shows weighted contributions, right plot shows unweighted contributions (with all parameters scoring 0 at T_L and 100 and T_U).

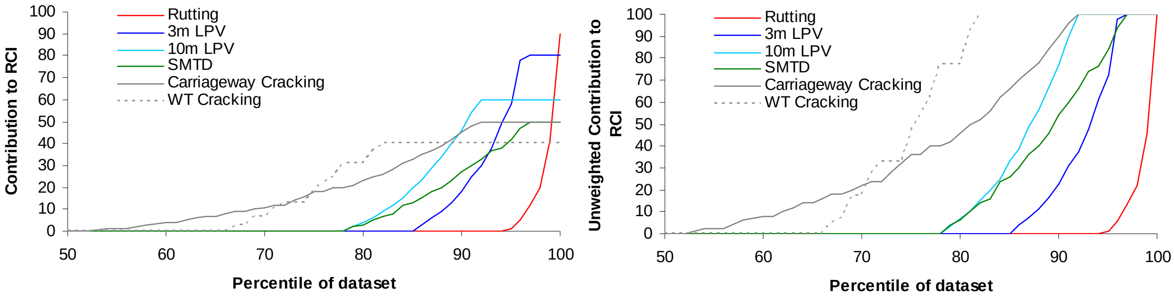


Figure 10: Contribution of each parameter to RCI, by percentile, for U roads in TRL sample dataset. Left plot shows weighted contributions, right plot shows unweighted contributions (with all parameters scoring 0 at T_L and 100 and T_U).

Proposed Action:

The thresholds used for calculation of the RCI are based on engineering objectives (e.g. what is a safe level of rutting?), combined with weightings deduced from a "common sense" approach. The thresholds were chosen, for the most part, for good reasons, and it would not be appropriate to adjust these without suitable evidence. However, it is clear that the thresholds and weightings employed in the RCI result in a disproportionate contribution by certain parameters (although the distributions alone do not show how the behaviour relates to the genuine state of the network in relation to each parameter).

Further investigation is therefore required. It is appropriate to carry out this investigation on an individual parameter basis. The following needs have been identified:

- To address the balance of the contribution of LPV to the RCI on all classes of road. Sections 3.2.4, 3.2.5, 3.2.6 and 3.2.7;
- To address the balance of the contribution of the two cracking parameters to the RCI. Sections 3.2.8 and 3.2.9;
- To ensure that the importance of rutting, which has been seen to affect a very small proportion of the data, is correctly recognised. Sections 3.2.10, 3.2.11 and 3.2.12;
- To further investigate the behaviour of the texture, for example the observed significant contribution on B, C and U roads, compared with A roads, to ensure that the contributions of texture is balanced across road classes. Sections 3.2.13, 3.2.14 and 3.2.15.

A summary of the findings and recommendations is presented in Section 3.2.16.

3.2.4 Representation of Longitudinal Profile Variance in the RCI

Observation:

Longitudinal Profile Variance (LPV) is felt by some engineers to be over represented in the RCI, especially in urban areas. Such areas often have many junctions where the cambers of the roads interact to produce features having high LPV scores, but which are not viewed as defects by the engineer. Numerical assessment of the RCI (Section 3.2.3, above) has also shown that LPV has a significant contribution to the RCI.

Evidence:

Longitudinal Profile Variance is a measure of the roughness of a road, assessed over different wavelength ranges. 10m LPV data contains information relating to the roughness of the pavement arising from profile features up to 10m in length. 3m LPV data contains information relating to the roughness of the pavement arising from profile features up to 3m in length. Any measurement of 10m LPV will therefore include some contribution from 3m LPV. If the short (3m) wavelength roughness is high enough there is a likelihood that it will contribute to the longer wavelength (10m) roughness. Hence a co-occurrence of high values of 3m and 10m variance may be expected, and consequently co-occurrence of high RCI scores for 3m and 10m variance.

Table 18 shows the co-occurrence of unweighted scores of 3m and 10m variance (within the sample dataset), expressed as proportions (percentages) of the dataset within scoring bands between 0 and 100. Chi-squared (χ^2) tests were performed on this data to determine how strong the association was between a given unweighted score of 3m LPV and a given unweighted score of 10m LPV.

3m LPV score	0	>0 and <20	>=20 and <40	>=40 and <60	>=60 and <80	>=80 and <100	100	
0	**70.81**	4.83	2.74	1.63	1.03	0.66	2.04	83.74
>0 and <20	1.81	**0.66**	0.49	0.34	0.26	0.18	0.75	4.48
>=20 and <40	0.91	0.43	**0.34**	0.26	0.20	0.15	0.67	2.96
>=40 and <60	0.49	0.28	0.25	**0.19**	0.15	0.11	0.55	2.01
>=60 and <80	0.26	0.18	0.17	0.13	**0.11**	0.10	0.47	1.43
>=80 and <100	0.14	0.14	0.12	0.10	0.09	**0.06**	0.39	1.04
100	0.20	0.30	0.35	0.36	0.32	0.29	**2.51**	4.34
	74.63	6.81	4.46	3.02	2.16	1.54	7.38	100

Table 18: Co-occurrence of unweighted scores of 3m and 10m LPV.

Results of χ^2 test:

- Testing independence of variables: $\chi^2 = 363514$, degrees of freedom. = 36, $p < 0.01$
- Percentage agreement : 74.7%
- Percentage above diagonal : 18.0%
- Percentage below diagonal : 7.3%
- Proportion test of difference between percent above and below the diagonal: $p < 0.01$

The χ^2 test detects a very strong association between the variables. The percentage of scores located down the diagonal in Table 18 (figures in **bold**) is high. However, there are more scores above the diagonal, suggesting that it is more likely to observe a higher 10m score with a low 3m score than it is to observe a observe a higher 3m score with a low 10m score. Most of the difference occurs where the 3m LPV scores 0 and the 10m LPV scores more than zero (but less than 60, these cells are highlighted in yellow).

The implications of the strong relationship are that there is quite a high probability of double counting the contribution of LPV within the RCI as a result of both the 3m and 10m variance being high. Using the current RCI thresholds and weightings, any subsection which had LPV values occurring in the cells shaded in pink (i.e. with high values for both 3m and 10m LPV) would definitely score over 100 and be classed as Red, overall. Subsections in the two cells with red text but no shading *might* trigger a report of Red, depending on their exact value. This means that somewhere between 4.04% and 4.49% of the sample dataset would score 100 points or more from LPV measurements alone.

However, it can be seen that there is also a significant frequency of occurrence of high scores for 10m LPV, with a zero score for 3m LPV (2.04%, shaded in light blue in Table 18). Therefore it does not seem appropriate to reduce the use of LPV to a single parameter (i.e. only 3m or 10m LPV). The two parameters can be triggered in different places, and so it is important to make sure that the correct one contributes in the correct situation.

Proposed Action:

The co-occurrence of 3m and 10m LPV suggests that there is a need to revise the approach taken to including LPV in the RCI. However, there is no evidence to suggest the removal of LPV from the RCI. It may be appropriate to group these values within the RCI.

Options for combining the 3m and the 10m LPV scores should be explored. However, it is proposed that the influence of individual values of LPV should not be reduced to a level below that that can be achieved by current individual values.

Test:

Examine the results of combining the 3m LPV and 10m LPV values in different ways:

- Weight both parameters equally at 0.8, only include the maximum score in the RCI calculation;
- Weight both parameters equally at 0.8, include mean score in the RCI calculation;
- Weight 3m LPV by 0.8, and 10m LPV by 0.6. Include only the maximum of the two scores;

Result:

Table 19 shows the mean RCI scores for each site, and the mean engineers' rating for each site visited as part of the workshop. These have been calculated using the Standard RCI (with manual crack data), the RCI calculated using the maximum of the two weighted LPV scores (both weighted at 0.8), and using the mean of the two LPV weighted scores (both weighted at 0.8). In general the effect of both these variations to the RCI model is to reduce the RCI reported. However, in some cases, the RCI increases. This is because the use of a weighting of 0.8 for 10m LPV (previously 0.6) enables this measure to contribute a higher value to the RCI.

Workshop Site ID	Average engineer proposed RCI	Standard RCI – manual cracking	RCI with max LPV (both 0.8 weighting)	RCI with mean LPV (both 0.8 weighting)
1(a)	127	190	166	151
1(b)	35	141	108	95
2	11	8	13	13
3	24	48	49	35
4	50	0	0	0
5	149	129	129	129
6	151	125	109	96

Table 19: RCI ratings of sites used in workshop and with different RCI models

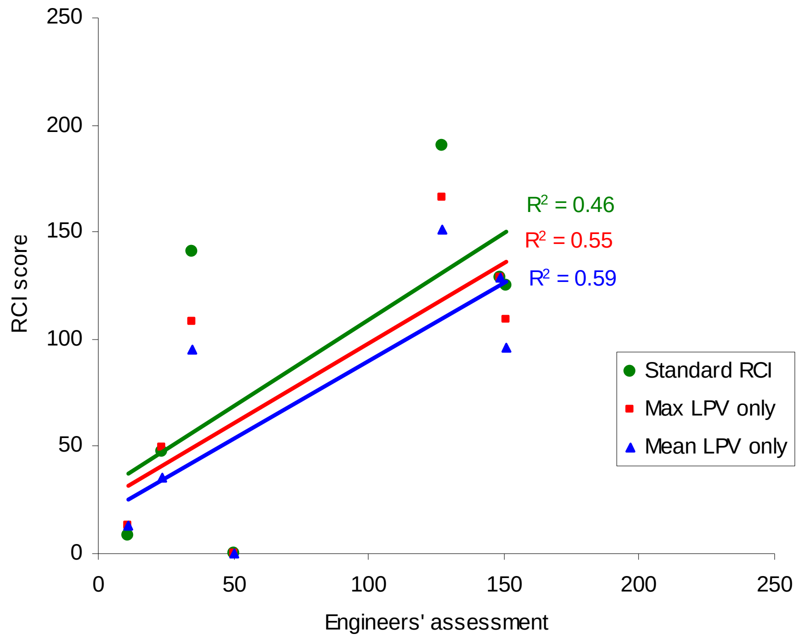


Figure 11: Correlations between average Engineers' site rating, and SCANNER RCI with different methods of including LPV data.

Figure 11 compares the RCI values obtained for each site with the corresponding engineers' proposed values. Again, it must be noted that this in itself is not sufficient evidence for any changes, and is presented here as part of the larger body of evidence.

We can see that the agreement between the RCI and the engineers' assessment is improved by combining the LPV parameters into a family, although the levels of agreement between the engineer's ratings, and the RCI are not perfect. Discussions with the engineers found that many found it difficult to interpret the LPV measure in terms of the condition of the road. Indeed, LPV defects can be difficult to visualise, or see in a walked site survey such as those performed as part of the workshop. We should not, therefore, expect complete agreement, but the reduction in disagreement is desirable.

The assessment on the workshop sites shows that both approaches to modifying the contribution of LPV to the RCI deliver improvements. However, the regression lines do not show that one approach delivers a much greater improvement than the other. Nevertheless, it is felt that the use of the maximum value would be preferable to that use of the mean. This would avoid over-smoothing the data, and reduce the risk of locations where there is high 10m variance, but low 3m variance, being under scored in RCI terms (2.04% of the data in Table 18).

Figure 12 shows how using only the maximum of the two weighted LPV parameters affects the reporting of RCI in the test dataset. It can be seen that the proportions of the network classed as Red decrease slightly for all road classes, as does the proportion classed as Green. If we apply the third test, that of weighting 3m LPV by 0.8, and 10m LPV by 0.6, the proportion which is classed as Red is further reduced.

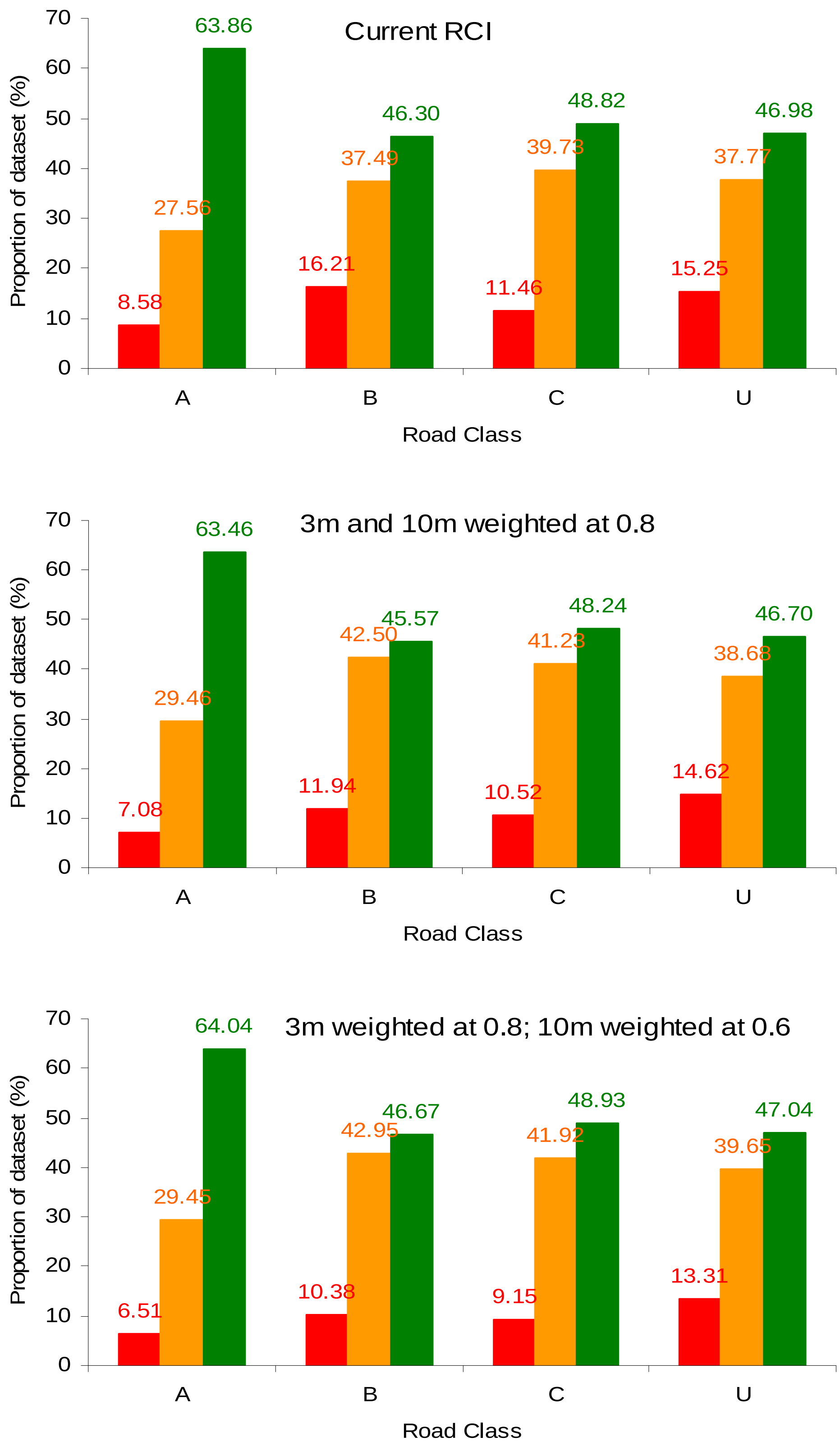


Figure 12: Proportion of TRL test dataset reported as red, amber and green using the Standard RCI (top plot), and the modified RCI (maximum LPV, both weighted at 0.8 (middle plot), maximum LPV 3m weighted at 0.8, 10m weighted at 0.6 (bottom plot)) on each road type

Recommendation:

Weight both 3m and 10m LPV at 0.8, and report only the maximum value.

This change would bring the following benefits

- By combining the LPV parameters into a family we remove the double counting of LPV which was resulting from the fact that 10m LPV and 3m LPV are such closely linked parameters.
- By weighting both parameters by 0.8 prior to determining which is larger we maintain the maximum influence of what is an important defect.
- By taking the maximum, rather than the mean of the parameters, we retain the ability to report high LPV in the RCI, even when only one parameter has triggered.

3.2.5 Relative importance of LPV in rural and urban environments on minor roads

Observation:

The existing SCANNER LPV thresholds for minor roads are based on the ones used in the SRMCS, which require that minor urban roads have a better ride quality than minor rural roads. Conversely, the Highways Agency approach requires rural trunk roads to have a better ride quality than urban trunk roads.

Evidence:

The SRMCS accepts worse roads in rural areas than in urban areas. The rationale behind this (which is currently under review in Scotland) appears to be that public expectation is higher in urban areas than in rural ones, where people are more tolerant of an uneven road profile. Consultations found that many engineers would accept different thresholds for LPV parameters to be used on rural roads to those which were used on urban roads.

Conversely the Highways Agency requires lower LPV values on rural trunk roads and motorways (IAN 42/05). The rationale behind this is that it is generally on these roads where speeds are higher and poor ride quality could be more uncomfortable, dangerous, and lead to further deterioration of the pavement.

Recent research by TRL (Benbow, et al, 2006) carried out to improve the data collected during SCANNER surveys, recommended the use of higher thresholds on urban roads than on rural roads, as also recommended by the Highways Agency. Further research by TRL carried out on behalf of the DfT into User Perceptions on Local Roads (Ramdas, et al, 2007) has found that people understand that there is a lot of trenching, patching and utility work performed in urban areas. They accept that this will impact on the resulting driving surface. This seems to suggest that the public would tolerate, or at least understand, less smooth roads in urban areas.

All the sites visited in the workshop were on A roads, therefore the only information available regarding minor roads (C and U) is at a network level, using the 16 LA database. Figure 13 and Figure 14 show the C road and Unclassified road network distributions of the sample dataset for different values of 3m and 10m LPV values respectively, along with the thresholds and weighting slopes for rural and urban minor roads. It can be seen that the distributions of the LPV values are very similar on both urban and rural roads. Therefore, regardless of the conflicting opinions and approaches to the requirements for ride quality on urban and rural roads, the distributions of ride quality actually present in the TRL dataset are comparable.

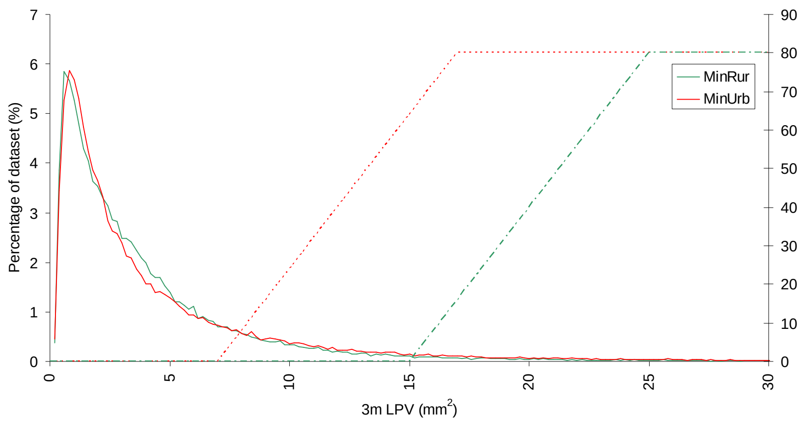


Figure 13: Distribution of 3m LPV values on minor (C and U) Rural and Urban roads. Also shown are the different thresholds and weighting slopes used for calculating the 3m LPV contribution to the RCI.

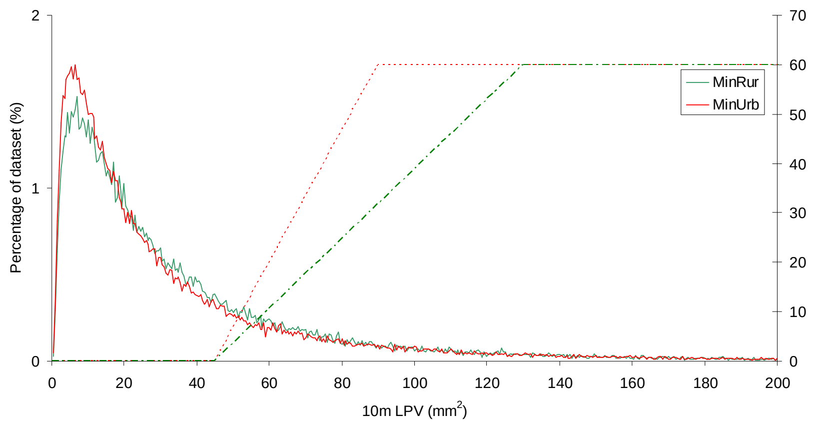


Figure 14: Distribution of 10m LPV values on minor (C and U) Rural and Urban roads. Also shown are the different thresholds and weighting slopes used for calculating the 10m LPV contribution to the RCI.

Proposed Action:

It is proposed that the RCI be modified in relation to the approach to assessing condition on urban and rural roads. The options proposed are:

1 – Change the thresholds for minor roads in urban areas only so that they are the same as those in rural areas;

2 – Swap thresholds for rural and urban minor roads so that rural roads are maintained to a higher condition than urban roads.

Test:

Tests were undertaken to show the effect of:

1 – Equalising thresholds at the current levels used for rural roads, meaning the contribution to the RCI from LPV on urban roads goes up more slowly.

2 – Reversing the thresholds, so that rural roads must be maintained to a higher standard than urban roads;

Result:

Figure 15 shows the proportions of the minor roads within the TRL test dataset which were classed as Red, Amber and Green by three different RCI models. The first of these, shown in the bold colours, is the Standard RCI. The second model used the same set of thresholds for minor road LPV measurements regardless of whether it was in a Rural or Urban area. The third model, shown by the unfilled in bars, shows the situation when the existing thresholds for Urban and Rural minor roads are reversed.

It can be seen that the proportion of Red roads has fallen when unified thresholds are used. This is because no change is experienced at all in Rural areas (the thresholds here are unchanged), but Urban areas are now using the same thresholds as Rural areas, and these new, relaxed, thresholds decrease the influence of urban areas.

When the thresholds are switched so that Rural roads must now meet more stringent standards than Urban ones, the overall effect on the network is very small. This is because although many of the Urban subsections which were previously Red are now Amber, and those Amber are now Green, there are an approximately equal number of Rural sites where the RCI classification has gone up, cancelling out the effect of the relaxing of LPV requirements in the Urban areas.

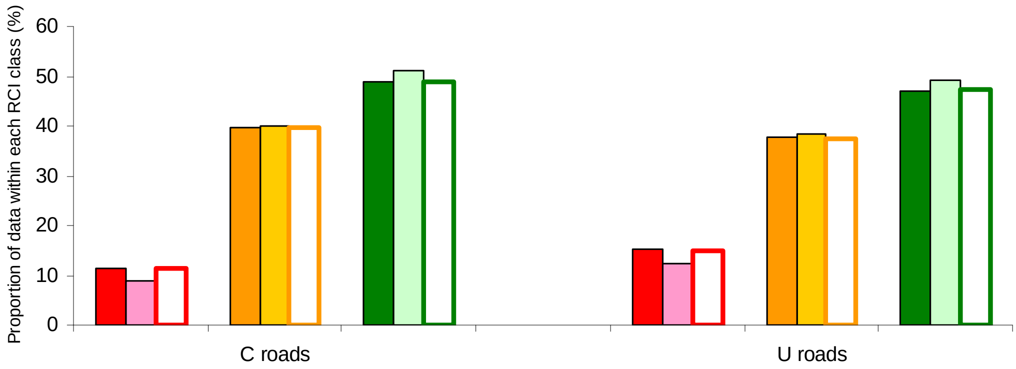


Figure 15: Proportions of C and U roads in TRL test dataset classed as Red, Amber and Green by three different RCI models.

Recommendation:

Equalise T_L and T_U for minor roads at upper level (as currently used on Rural roads) as no need to distinguish between rural and urban.

This change would bring the following benefits

- It simplifies the model
- It removes ambiguities and confusion over whether Urban or Rural roads should have to be maintained to the higher LPV standard
- The LPV scores on urban roads will reduce, reducing the pressure on LAs who feel they are suffering from artificially high RCI values, due to LPV features which they do not consider as defects, and which would not be maintained
- It maintains a sensible network distribution of Red, Amber and Green values.

3.2.6 The thresholds for LPV for B, C and U roads

Observation:

The RCI thresholds established for A roads for the RCI were obtained from the thresholds for LPV used on Highways Agency roads. These were developed from the research programme, including user perception studies. It is not certain that these are the most appropriate thresholds for local A roads.

The thresholds for LPV for B roads are the same as those applied to A roads, which implies that similar levels of ride quality are required for both A and B roads. TRL received a considerable amount of feedback from engineers which suggested they view LPV as less important on minor roads than on A roads, and that a lower level of ride quality would be expected and accepted as the hierarchy or classification of the road decreased. There is therefore probably even more uncertainty in the selection of these thresholds.

The thresholds for LPV for C and U roads were not developed on the basis of any user perception studies. It was known, when they were established, that they would be subject to subsequent review. Further data is now available on these roads that enables us to challenge these thresholds.

Evidence:

Figure 16 and Figure 17 show the distribution of 3m and 10m LPV values respectively for the test dataset, when split into A, B, C and U roads. The distribution of LPV values on A roads and B roads is very different. It can be seen in the Figures below that B road LPV values are distributed much more like C roads than A roads. Currently the RCI requires that A and B roads are maintained to the same standard of longitudinal profile. In light of the distributions shown in Figure 16 and Figure 17, this requirement becomes questionable.

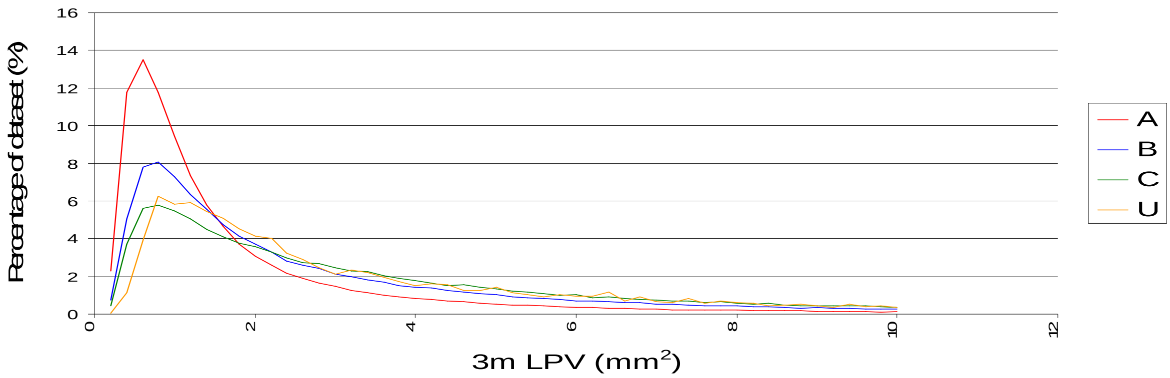


Figure 16: Distribution of 3m LPV values for A, B, C and U roads.

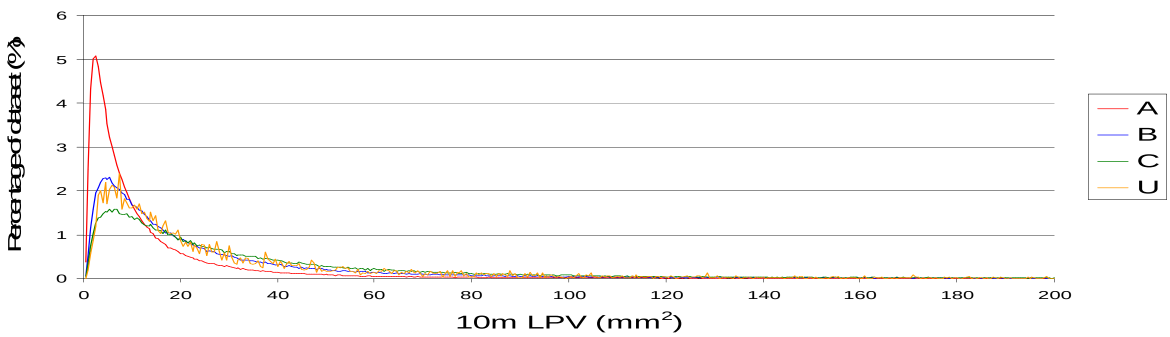


Figure 17: Distribution of 10m LPV values for A, B, C and U roads.

Research carried out on behalf of the DfT into the use of shape data on local roads (Benbow et al, 2006) recommended a range of thresholds for use with LPV data for local roads. In this work Benbow et al. determined that the thresholds used for A roads, derived from HA research, were appropriate for local A roads. However, the research went on to recommend a further set of thresholds for lower classes of road. These thresholds are shown in Table 20. Clearly the application of the wide range of thresholds listed in Table 20 would be impractical for the RCI. However, there is a need to select an appropriate range of thresholds from this table. It is proposed that these be selected on the following basis:

- The work of section 3.2.5 has already recommended using similar thresholds for urban and rural roads.
- SCANNER has never distinguished between dual or single carriageway roads. Indeed, there is no easily accessible data on this single or dual status and the proportions of dual C, or U (or B) roads will be very small.
- The current threshold for A roads (which were confirmed in the research), are those recommended for rural single roads.

Therefore it follows that the rural single values would be appropriate for assessment as the remaining thresholds.

		A				B				C				Other			
		RD	UD	**RS**	US	RD	UD	**RS**	US	RD	UD	**RS**	US	RD	UD	**RS**	US
3m MA variance	c1	1.3	1.5	**1.5**	2.5	1.7	1.9	**1.9**	3.2	2.1	2.5	**2.5**	4.1	2.55	2.94	**2.94**	4.91
	c2	4	4	**4**	7	5.1	5.1	**5.1**	8.9	6.6	6.6	**6.6**	11.6	7.85	7.85	**7.85**	13.74
	c3	6	7	**7**	12	7.6	8.9	**8.9**	15.3	9.9	11.6	**11.6**	19.8	11.77	13.74	**13.74**	23.55
	c3.5	8	10	**10**	17	10.2	12.7	**12.7**	21.7	13.2	16.5	**16.5**	28.1	15.70	19.62	**19.62**	33.36
10m MA variance	c1	4	7	**7**	15	5.1	8.9	**8.9**	19.1	6.6	11.6	**11.6**	24.8	7.85	13.74	**13.74**	29.43
	c2	16	21	**21**	45	20.4	26.8	**26.8**	57.4	26.4	34.7	**34.7**	74.4	31.40	41.21	**41.21**	88.30
	c3	26	38.5	**38.5**	68	33.1	49.1	**49.1**	86.7	43.0	63.6	**63.6**	112.4	51.02	75.55	**75.55**	133.44
	c3.5	36	56	**56**	90	45.9	71.4	**71.4**	114.7	59.5	92.6	**92.6**	148.8	70.64	109.89	**109.89**	176.61

Table 20: Proposed threshold values for different types and classes of road in rural and urban environments, from shape research (Benbow, et al, 2006).

<u>Proposed Action:</u>

Investigate the effect of using the new threshold values for B, C and U roads.

<u>Test:</u>

The effects of the proposed changes were tested by calculating the RCI with T_L and T_U different for A, B, C and U roads:

(1) Run with T_L and T_U for B, C and U roads set following the thresholds derived from SCANNER research into the Shape of local roads (Benbow, 2006), as described above.

<u>Result:</u>

Figure 18 shows the proportions classed as Red, Green or Amber for each class of road when using the existing RCI definition. Figure 19 shows the data obtained using the modified thresholds derived from the Shape research. It can be seen in that the effect of modifying the thresholds on B roads is to reduce the proportion of red lengths, with an associated increase in green lengths. The reduction in red is significant, due to the difference in the distribution of LPV values on B and A roads. The amount of Red is seen to increase on C roads, at the expense of Green. Very little change is observed in the U roads.

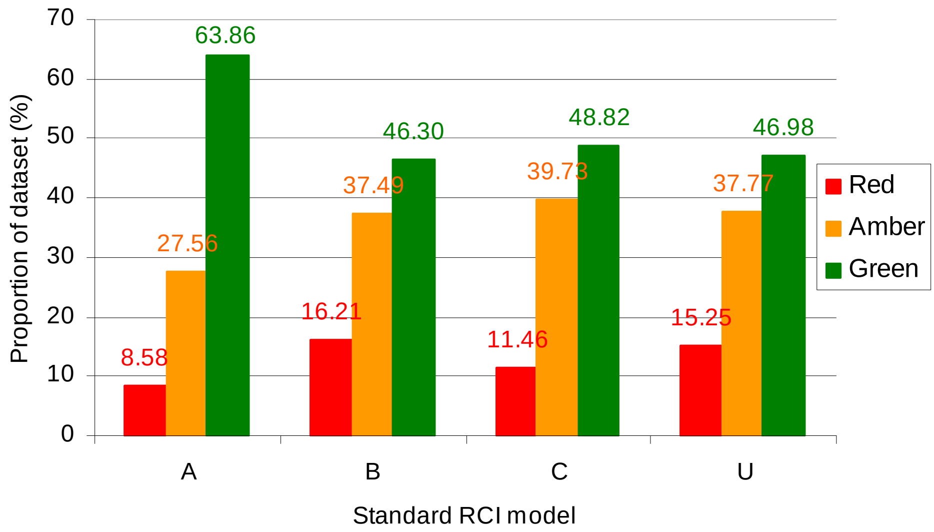


Figure 18: Network proportions of Red, Amber and Green for A, B, C and U roads using the existing RCI.

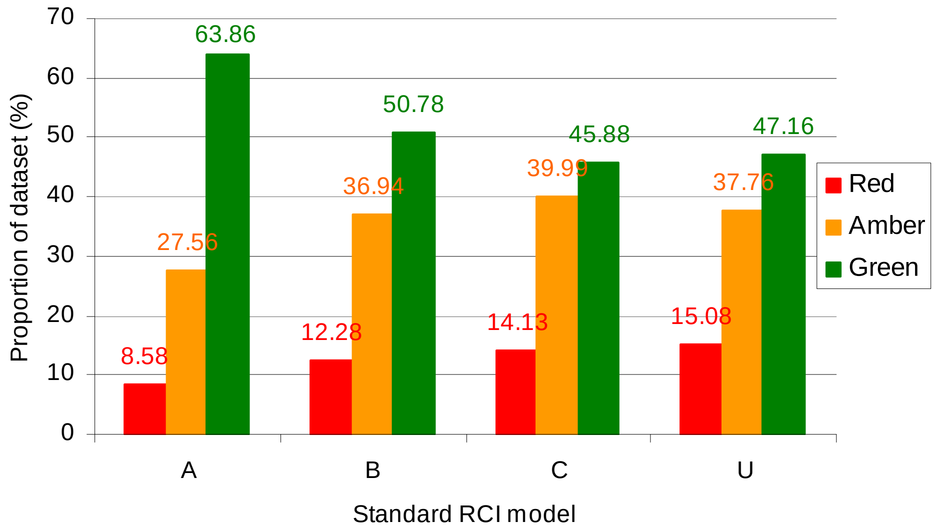


Figure 19: Network proportions of Red, Amber and Green for A roads, and for B roads using the LPV thresholds as recommended in the Shape research.

Recommendation:

Modify the thresholds for B, C and U roads to reflect the result of the TRL research into the Shape of local roads (Benbow, 2006), with no distinction between urban and rural environments. These are shown in Table 21.

These changes would bring the following benefits

- Removing the requirement to maintain B roads to the same standard of ride quality as A roads (and reflecting their current level of ride quality);
- Reducing the proportion of B roads within the dataset classed as Red (this falls by approximately 4%);

- Thresholds for C and U are selected based on more evidence than was previously the case;
- Maintains sensible network distribution.

Class	Existing RCI LPV thresholds				Class	Recommended RCI LPV thresholds			
	3m		10m			3m		10m	
	T_L	T_U	T_L	T_U		T_L	T_U	T_L	T_U
A	4	10	21	56	**A**	4	10	21	56
B	4	10	21	56	**B**	5	13	27	71
C/U urban*	7	17	45	90	***C****	7	17	35	93
C/U rural*	15	25	45	130	***U****	8	20	41	110

Table 21: Existing and recommended LPV thresholds for use in the RCI. *Original thresholds used an urban/rural split for minor roads, proposed thresholds split by class, not environment. This makes a direct comparison of the thresholds less simple.

3.2.7 Effect of all proposed LPV changes

The following alterations are proposed for the way in which the Revised RCI should include LPV data:

- Weight both the 3m and 10m LPV at 0.8, and report only the higher scoring;
- Remove the distinction between rural and urban roads;
- Use separate thresholds for A, B, C and U roads;
- Use the thresholds as recommended in the Shape research, and shown in Table 21.

3.2.7.1 Impact of all proposed LPV changes

Figure 20 shows the proportions of the TRL test dataset having RCI values of Red, Greed and Amber using the current RCI. This can be compared with results obtained following the above modifications shown in Figure 21

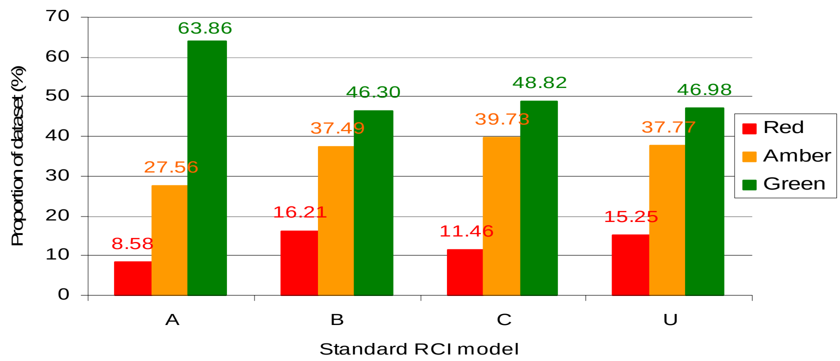


Figure 20: Network proportions of Red, Amber and Green for A, B, C and U roads using the existing RCI.

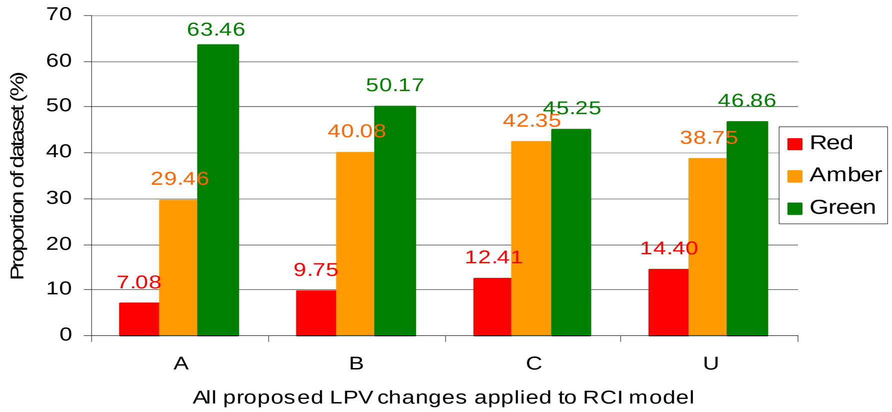


Figure 21: Network proportions of Red, Amber and Green for A, B, C and U roads using all proposed changes to the way in which the RCI handles LPV data.

Number of Red in entire dataset with Existing RCI:	106364 (11.4%)
Number of Red in entire dataset with Proposed RCI:	98883 (10.6%)
Change in number of red:	-7481 (0.8%)

3.2.8 Poor crack measurement in general

Observation:

The measurement of cracking in SCANNER surveys is one of the acknowledged weaknesses of the system. The measurements are prone to including a high proportion of false positives due to a range of features such as white lines, ironwork, patching, and other non-crack features.

Evidence:

Throughout the duration of the SCANNER surveys one of the contractors has experienced serious problems with the measurement of cracking, showing how challenging it is to measure this parameter accurately and reliably. Recent research into the use of cracking in SCANNER surveys has found that the automatic measurement of cracking as used in SCANNER surveys has scope for considerable improvement. This is an area of ongoing research, both within and without the SCANNER community (McRobbie and Wright, 2006; Furness, et al, 2006).

If the cracking data is unreliable then the data used to obtain the RCI will be poor, which will result in the quality of the output from the RCI being degraded. This could lead to a loss of confidence in the SCANNER system, which would be hard to regain.

The Highways Agency does not include cracking in the current Performance Indicator, due to concerns about the accuracy of its measurement. Indeed the use of automatically derived cracking data in network condition monitoring is something which has not been widely adopted anywhere in the world, with most countries stopping short of full automation, and requiring some manual intervention or supervision for their crack measurement systems.

Proposed Action:

Removal of crack data from the RCI calculation.

Test:

The proposal was tested by examining the effect of removing all cracking data from the RCI calculations on the workshop sites. The average site scores obtained were compared with those obtained with cracking included. The effect of removing cracking was also investigated using the network data.

Result:

Table 22 shows the results of removing cracking altogether from the RCI for the workshop sites. It was found that the RCI dropped substantially when cracking was removed, especially where the sites were in generally poor condition anyway. For example the RCI values of sites 5 and 6 dropped from classing the sites as Red, to Amber when the crack data was removed from the RCI calculations. Figure 22 plots the RCI scores for each of the workshop sites against the corresponding engineer's assessments. This data is shown with both automatic and manual cracking data, and with the exclusion of all of cracking data in the calculation of the RCI. It can be seen that, by excluding all crack data from the calculation, the agreement between the RCI and the engineers' judgement becomes significantly worse than when manual crack data is used to calculate the RCI. It seems clear that a measure of cracking is required in the RCI, and when this data is correct it brings clear benefits.

However for this dataset it is difficult to determine whether inclusion of the automatic cracking data provides any benefit over the exclusion of cracking from the RCI. This is probably because of the influence of poor crack measurements over part of the sites. It must be noted that the sites and data used in the workshop may not be fully representative of the state of the network. We cannot assume that the poor performance of the automatically derived crack data on some of these sites is representative, and we do not feel this is justification to remove cracking from the RCI, as the RCI is undoubtedly improved by the inclusion of cracking data, where the crack data is correct.

Workshop Site ID	Average engineer rating	RCI with automatic crack data	RCI with manual crack data	RCI with no crack data
1(a)	127	215	190	127
1(b)	35	185	141	128
2	11	9	8	3
3	24	115	48	44
4	50	69	0	0
5	149	97	129	81
6	151	177	125	94

Table 22: RCI ratings of sites used in TRL RCI Workshop and with different RCI models

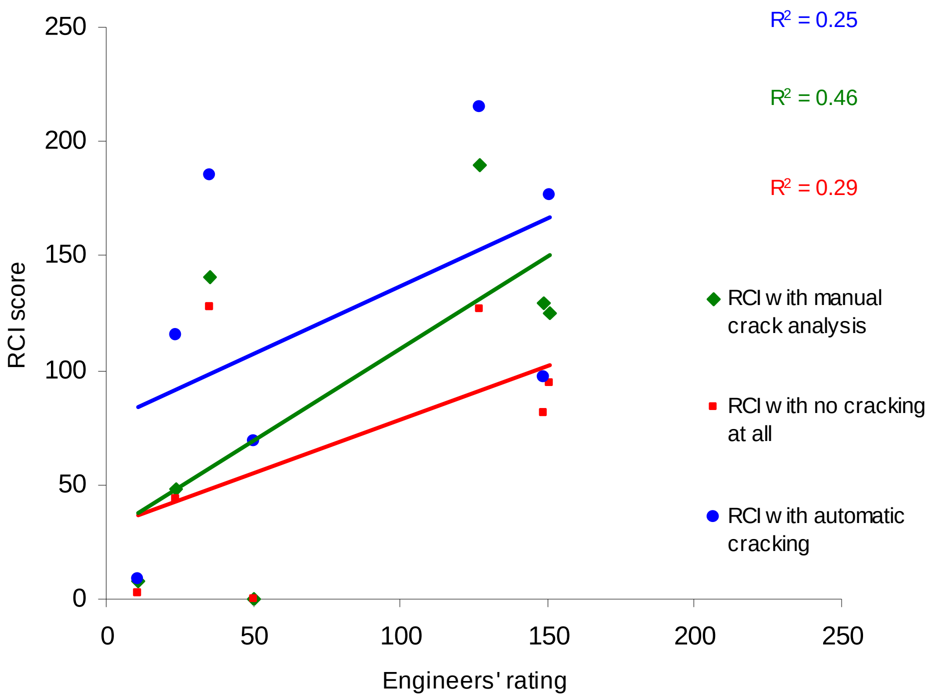


Figure 22: Relationship between average Engineers' site rating, and SCANNER RCI with and without the inclusion of any cracking data.

Figure 23 shows the effect on the network of removing cracking data from the RCI model. It can be seen that the proportions of Red and Amber decrease quite significantly, with the amount of Green increasing to compensate. This reflects the large contribution that cracking has to the RCI, as discussed in Section 3.2.3.

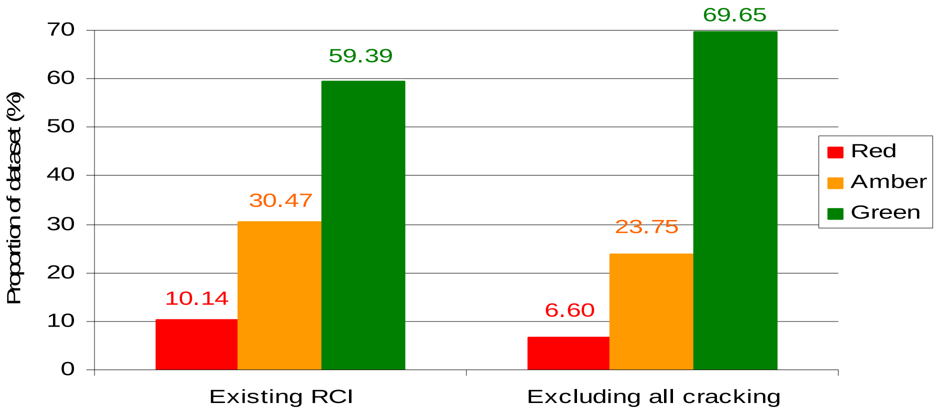


Figure 23: Proportions of TRL test dataset classed as Red, Amber and Green when using the Standard RCI model, and when excluding all cracking from the calculations. (Figures calculated excluding DCL data).

Recommendation:

Although the cracking data is subject to some concern, it is too important to engineers to leave out of the RCI completely. There is therefore a need to retain some measurement of cracking in the calculation of the RCI.

This will bring the benefit of ensuring that the RCI gives a more meaningful indicator to the engineer, who is interested in the presence of cracking. Furthermore, where the crack data is good, then the level of agreement between the RCI and an engineer's opinion on a given site is usually increased.

3.2.9 Representation of cracking within the RCI

Observation:

Cracking contributes toward a non-zero RCI score on more of the network than any other parameter (See Section 3.2.3).

Evidence:

It was shown in Figure 6 that approximately 27% of the network is affected by cracking at a level which affects the RCI calculation. On U roads as much as 48% of the network is affected by cracking.

It must be understood that SCANNER wheeltrack cracking is not the same as the CHART definition of wheeltrack cracking which engineers may be familiar with. SCANNER wheeltrack cracking is not restricted to cracking running longitudinally along the wheeltrack. Apart from some restrictions on the proportions of a crack within and without the wheeltrack for it to be counted as wheeltrack cracking, almost all cracking which is measured in the area defined as the wheeltrack during a SCANNER survey is reported as wheeltrack cracking.

A fuller explanation of the principles involved in the calculation of the area of cracking reported is given in Appendix C. Consideration of Appendix C shows that the intensity of carriageway cracking reported by SCANNER contains within it the intensity of wheeltrack cracking. This means that there may be an element of double counting of cracking, and over representation of cracking in the RCI, as was the case in the LPV calculations discussed in Section 3.2.4. This double counting of wheeltrack cracking means we would expect a high degree of co-occurrence between high or low values of wheeltrack cracking and corresponding high or low values of carriageway cracking. This is shown in Table 23. Chi-squared (χ^2) tests were performed on this data to determine how strong the association was between a given value of carriageway cracking and a given value of wheeltrack cracking.

Carriageway cracking score	Wheeltrack score: 0	>0 and <20	>=20 and <40	>=40 and <60	>=60 and <80	>=80 and <100	100	
0	**70.24**	1.43	0.88	0.12	0.00	0.00	0.00	72.67
>0 and <20	6.35	**0.99**	1.40	0.83	1.26	0.32	0.71	11.86
>=20 and <40	1.79	0.30	**0.43**	0.28	0.45	0.22	1.37	4.84
>=40 and <60	0.97	0.12	0.24	**0.13**	0.27	0.10	1.39	3.23
>=60 and <80	0.48	0.06	0.10	0.07	**0.13**	0.06	1.09	2.00
>=80 and <100	0.22	0.03	0.05	0.03	0.07	**0.03**	0.78	1.21
100	0.60	0.05	0.10	0.06	0.14	0.05	**3.20**	4.19
	80.65	2.98	3.21	1.51	2.32	0.79	8.55	100

Table 23: Co-occurrence of high, moderate and low unweighted scores of carriageway and wheeltrack cracking.

<u>Results of χ^2 test</u>

Testing independence of variables: χ^2 = 637286, degrees of freedom = 36, $p < 0.01$
Percentage agreement: 75.1%
Percentage above diagonal: 13.0%
Percentage below diagonal: 11.9%
Proportion test of difference between percent above and below the diagonal: $p < 0.01$

The χ^2 test shows a very strong association between the variables. The percentage of scores located down the diagonal (figures in **bold**) in Table 23 is high. There are more values above the diagonal than below, suggesting that there is a likelihood of obtaining high unweighted scores of wheeltrack cracking without high carriageway cracking (note that this is likely to be a result of the method of calculation of wheeltrack cracking). A large proportion of the disagreement occurs where the wheeltrack cracking scores 0 and the carriageway cracking scores greater than 0 and less than 20 (highlighted in yellow). Furthermore, a relatively large proportion of scores (0.6%) are recorded as 0 for wheeltrack cracking and 100 for carriageway cracking, which occurs when 16 or more grid squares outside the wheeltracks contain cracking.

In addition to the double counting of cracking identified in the wheeltracks there is a related issue concerning the reliability of the measurement of cracking in the wheeltrack. Furness et al., (2006) have reported that, whilst the method of calculation of wheeltrack cracking is appropriate, a high proportion of the reported wheeltrack cracking is calculated from data arising from false positive detections of cracking.

Proposed Action:

It is proposed to reduce the influence of double counting of cracking by one of the following methods:

- Use a family approach and report only the maximum of the two weighted crack parameters, with their current weightings;
- Use a family approach and report only the maximum of the two weighted crack parameters, but with both parameters weighted at 0.6;
- Remove wheeltrack cracking from the RCI calculation, and weight carriageway cracking at 0.6.

Note that the workshop identified cracking to be an important parameter. Reducing the reporting of cracking to one parameter could downgrad its influence on the RCI. Therefore the above proposals include raising the weighting of the single reported crack parameter to 0.6.

The removal of the carriageway cracking and retaining only the wheeltrack cracking was not considered as this would retain all the problems with the high proportion of false positives associated with wheeltrack cracking, and would introduce a further layer of uncertainty (is it what an engineer would recognise as wheeltrack cracking?) into an already uncertain parameter (is it genuine cracking?).

Test:

The following tests have been carried out

- An investigation of the effect of the family approach, and exclusion of wheeltrack cracking on SCANNER workshop sites.
- An investigation of the effect of proposed changes to the RCI on the test dataset of 16 Local Authorities.

Result:

Figure 24 shows the RCI values calculated at 10m intervals for the sites in the workshop. The average rating for each of the sites is also presented in Table 24. These have been calculated using the Standard RCI, the RCI excluding wheeltrack cracking altogether but including carriageway cracking weighted at 0.6, the RCI reporting only the maximum of the two crack parameters (using their current weightings of 0.5 for carriageway and 0.4 for wheeltrack cracking), and the RCI set to report the maximum of the two crack parameters (weighting both at 0.6).

Workshop Site ID	Average engineer rating	Existing RCI with manual crack analysis	RCI with no WT cracking	RCI with max cracking only (0.5)	RCI with max cracking only (0.6)
1(a)	127	190	126	165	175
1(b)	35	141	94	136	137
2	11	8	9	9	10
3	24	48	42	47	47
4	50	0	0	0	0
5	149	129	107	110	118
6	151	125	91	111	115

Table 24: RCI ratings of sites used in TRL RCI Workshop and with different RCI models regarding inclusion of cracking data

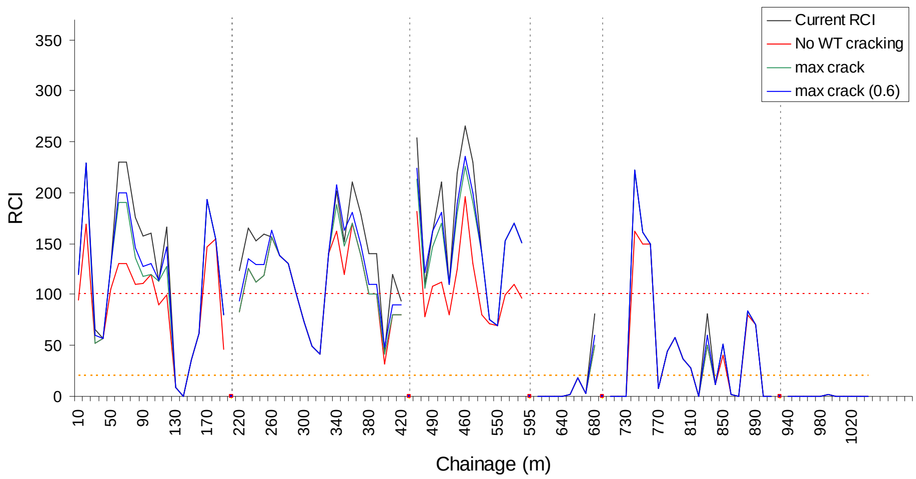


Figure 24: RCI values of Bracknell workshop sites calculated using standard RCI model, and the three proposed methods of handling crack data. (site order is 6, 5, 1, 2, 3, 4)

As can be seen in Figure 24, and Table 24, where only low levels of cracking were present the changes to the RCI model have had little effect on the results (Sites 2 and 4). In general the effect of both variations to the RCI model is to reduce the RCI reported, however, in one case (Site 2), the RCI goes up very slightly. This is because the reported cracking is now weighted by 0.6 rather than 0.5 or 0.4.

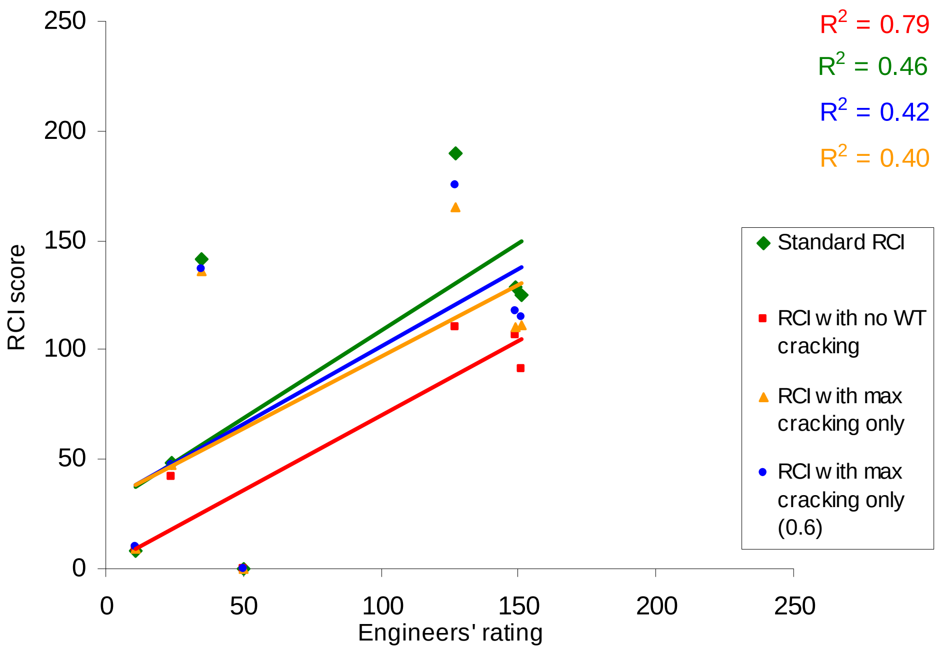


Figure 25: Correlations between average Engineers' site rating, and SCANNER RCI with different methods of including cracking data.

Figure 25 shows the average RCI values obtained for each of the RCI workshop sites using a number of different RCI models, and the corresponding engineers' assessments of the sites. This is, once again, not presented as strong evidence, but it can be seen that, on these sites, the results obtained by excluding wheeltrack cracking altogether from the RCI calculation have the best agreement with the engineers' judgement. Figure 26 shows the effect of removing wheeltrack cracking from the RCI, but increasing the weighting of carriageway cracking to be 0.6, for 14 of the LAs in the test dataset (excluding the two DCL surveyed authorities).

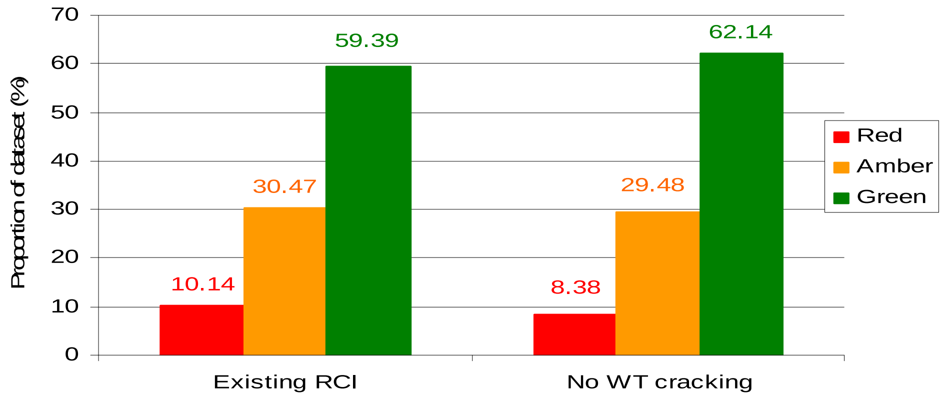


Figure 26: Proportions of TRL sample dataset classed as Red, Amber or Green when using the Standard RCI and the RCI model excluding wheeltrack cracking, and weighting the carriageway cracking at 0.6. (Figures calculated excluding DCL data).

Recommendation:

- Remove wheeltrack cracking from the RCI model, but continue to include carriageway cracking data, weighted more strongly at 0.6.

This change would bring the following benefits

- It removes effect of high false positive rate in wheeltrack cracking;
- It removes effect of double counting of cracks in wheeltrack;
- It provides an RCI in better agreement with engineers' opinions;
- It is a simpler approach for RCI model;
- It maintains sensible network distributions of Red Amber and Green.

3.2.10 Significance of Rutting

Observation:

Due to the way the RCI has been designed it is currently impossible for any single contributing parameter to trigger a Red value in the absence of another contributory defect.

Feedback from a number of engineers has indicated that there is perhaps sound justification for allowing certain defects, particularly rutting, to trigger a subsection as Red even in the absence of any other defect.

Evidence:

Rutting is currently weighted with a maximum score of 90 points for rut depths at or above T_U. There has been considerable feedback suggesting that many engineers would prefer the RCI to be able to show lengths of severely rutted roads as Red, even where no other defects are present. This is because rutting is a safety defect when very deep. The engineers were of the opinion that, although it may happen only very rarely, a length of road with no defects other than very serious rutting would be of concern to them.

One of the workshop sites, Site 5 (see Appendix A for full details of Workshop sites), exhibited significant rutting, which the attendees felt should trigger action. Site 5 also exhibited other defects at a minor level, but engineers expressed the view that the rutting alone would be enough for them to be concerned about the site.

Proposed Action:

It is proposed that the RCI be modified to allow a 10m subsection to be classed as Red based solely on rutting:

- Change the Reliability and Importance factors **R** and **I** to both equal 1 (one), and allow a score of 100 at T_U. This will change existing slopes slightly. However, at the network level it was shown in Figure 6 that rutting affects less of the network (~11%), in terms of contribution to RCI, than any of the other parameters. It is felt that changing the model to allow rutting to trigger red on its own would be very unlikely to affect much of the network.

Test:

The following tests were carried out:

- Count the number of subsections which are Red for no reason other than rutting;
- Count the number now Red which were not before (to test the effect of changes to slopes);
- Investigate whether those changed are sensible (among existing rutting) or do they look anomalous?

Result:

When the RCI values for the workshop sites were calculated with and without allowing rutting to score a maximum of 100 points only one 10m subsection changed its colour classification, and moved from Green to Amber (score of 18.8 moved to 20.2). No sections within the workshop sites changed from Amber to Red. Network wide, only 619 lengths (out of nearly 1 million) were found to be classed as Red for no reason other than heavy rutting.

Number of Red in entire dataset with Standard RCI:	106364 (11.41%)
Number of Red in entire dataset with Modified RCI:	108595 (11.64%)
Increase in number of red:	2231 (0.24%)
Number of Red solely due to rutting:	619 (0.07%)

However, as well as discovering how much of the network would be affected by allowing rutting to score 100 points, it was also important to find out which sites these would be, and whether or not the behaviour looked sensible, in particular whether the modification gave rise to localised "rogue rut values" being erroneously reported.

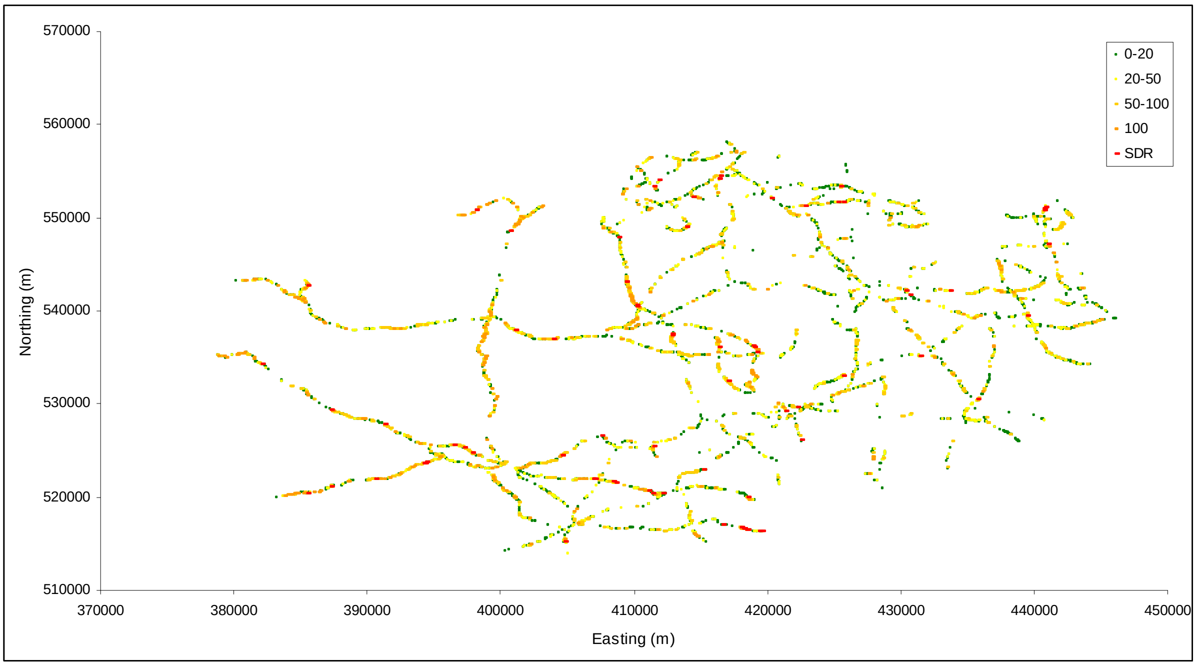


Figure 27: Selection of Durham CC data showing weighted rut scores, with those 10m subsections which would be Red solely on the basis of a high rut depth highlighted.

Figure 27 shows a selection of data from Durham CC. This plot shows the weighted rut depth contributions to the RCI displayed using their GPS coordinates. By plotting the data in this way we can see whether or not the instances of Red sections caused by nothing other than rutting were occurring in isolation, away from any significant rutting, or were occurring in areas where there was significant rutting reported for lengths of road. Examination of the data surrounding such locations suggested that the vast majority of rut-only Red subsections occur in areas which are significantly rutted. These lengths are almost always above T_L for a number of 10m subsections, and are usually significantly above T_L. It was very rare to find a subsection which was scoring 100 points for rutting in complete isolation from any other contributory rut depths.

Recommendation:

Allow rutting to score 100 points, enabling it to trigger Red subsections on its own.

Change weighting factors (**R** and **I**) to adjust maximum score from 90 to 100.

Currently **I = 0.9** and **R = 1**

Set **I=1** and **R=1**.

This change would bring the following benefits

- Allows the RCI to reflect the importance of severe rutting, as desired by engineers;
- Affects very little of the network, so does not result in large changes to the indicator.

3.2.11 Rut thresholds

Observation:

Large rut depths present safety hazards wherever they occur on the network. Because of the current thresholds set with the RCI it is possible to have large rut depths on C or Unclassified roads, particularly in rural environments, without triggering a large score in the RCI.

Evidence:

As can be seen in Table 25 it is possible for a road to exhibit 18mm of rutting and still be Green, if it is a minor rural road.

Road Class	Environment	T_L	T_U	Max still Green
A or B	-	10	20	**12**
C or U	Urban	12	25	**14.6**
C or U	Rural	15	30	**18**

Table 25: Thresholds and maximum rut depths allowable without triggering Amber for any 10m subsection in absence of other contributory defects.

Figure 28 shows the distributions of rut depths on the dataset of 16 LAs. It can be seen that there is very little difference in the distributions of the rut depths between the different road classes or environments. These similar distributions provide no support to justify applying higher thresholds for rutting on minor roads. Furthermore, the engineers at the workshop questioned why the thresholds for rutting are so markedly different, or indeed why they were different at all. The engineers felt there was no reason for the different classes and environments to accept different levels of rutting.

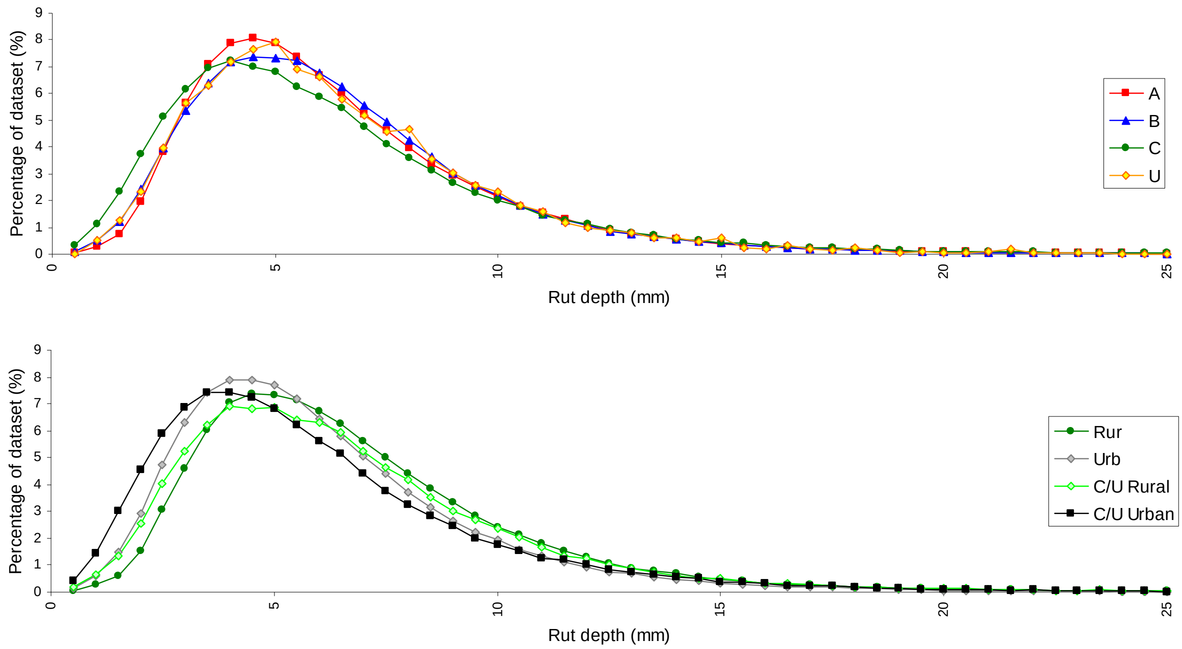


Figure 28: Distribution of rut depth on TRL test dataset, shown for A, B, C and U roads (top plot) and for Rural or Urban environments (bottom plot).

Proposed Action:

It is proposed that the rut thresholds be unified across all classes and environments of road at the levels used for A and B roads (T_L = 10, T_U = 20).

Test:

The testing has assessed the effect of the revised thresholds on the network distributions of Red, Amber and Green.

Result:

The use of a single set of thresholds changes the proportions of Red, Amber and Green on C and U roads, but not A or B roads as it is not proposed that the thresholds be altered on these roads. As can be seen in Figure 29, revising the thresholds very slightly increases the percentage of minor roads placed in Amber and Red. This may not be a large effect on the reported condition of the network.

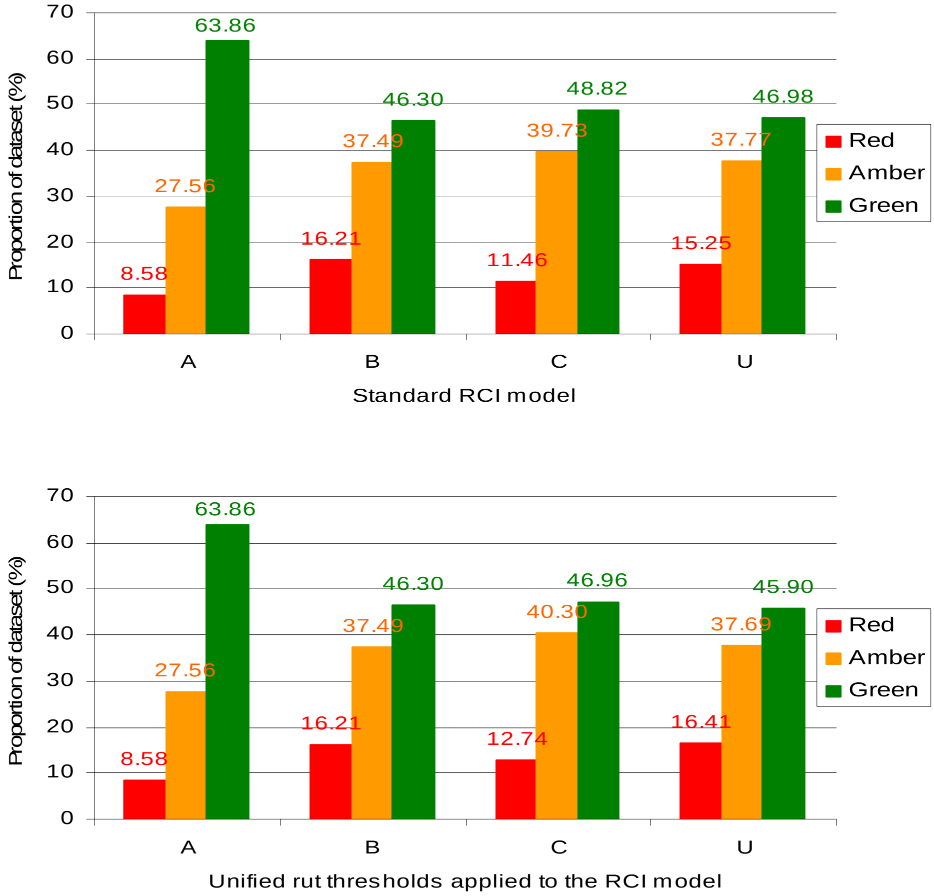


Figure 29: Red, Amber and Green proportions of A, B, C and U roads with existing RCI model (top), and with a single set of thresholds for rut depth applied regardless of class or environment (bottom).

Recommendation:

Set all rut thresholds for T_L and T_U to a single value, as currently used on A and B roads.

The weightings for rutting will not be adjusted for the different classes or environments as rutting is equally important regardless of where it occurs.

This modification will bring the following benefits:

- The use of a single, lower set of thresholds increases the importance and impact of rut depth on minor roads, especially in rural areas.
- It unifies the approach to rutting across the network, reflecting the importance considerations of the engineers;
- It does not change RCI performance drastically over the whole network (1.2% extra Red);
- It provides a simpler RCI model.

3.2.12 *Effect of both proposed rut changes*

The following alterations are proposed for the way in which the Revised RCI should include rut data:

- Allow rutting > T_L to contribute 100 points to RCI;
- Use a single set of thresholds for all roads, regardless of class and environment;
- Set $T_L = 10$, $T_U = 20$.

3.2.12.1 Impact of all proposed Rut changes

Figure 30 compares the proportion of the TRL test dataset having RCI values of Red, Greed and Amber using the current RCI with those obtained using the RCI following the above modifications.

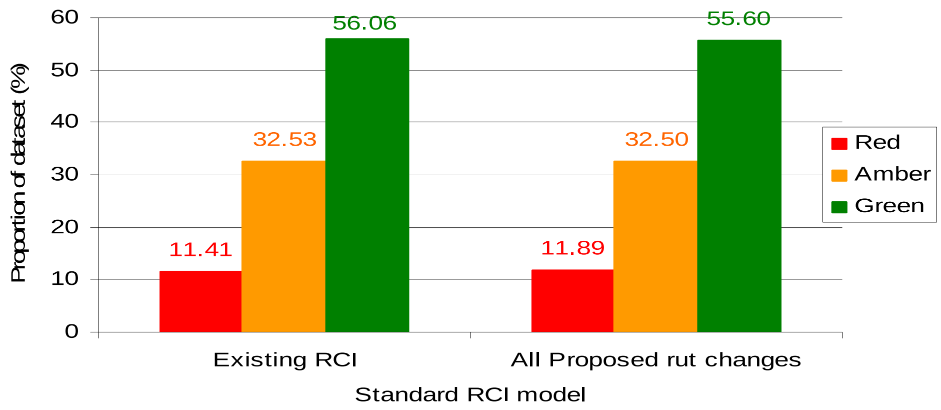


Figure 30: Comparison of existing RCI with RCI modified to include all proposed changes to the use of rutting data.

Number of Red in entire dataset with Standard RCI:	106364 (11.41%)
Number of Red in entire dataset with Modified RCI:	110899 (11.89%)
Increase in number of Red:	4535 (0.49%)
Number of Red solely due to rutting:	771 (0.08%)

3.2.13 The suitability of the texture thresholds

Observation:

Texture currently uses a single set of thresholds and weightings on all classes and environments of road.

Evidence:

Texture depth is able to give some indication of high-speed skidding resistance properties of a length of road. This information is likely to be far more relevant on A roads, which typically convey higher speed traffic than lower classes. Feedback from the engineers suggested that they viewed low texture depths more seriously on roads which were likely to carry high speed traffic, and that higher texture was needed on these roads than in, for example, urban residential areas.

Recent research carried out by the Highways Agency, which investigated the relationship with friction, has recommended that the thresholds for Trunk Roads increase. These increases have been adopted in IAN42/05.

Proposed Action:

It is proposed that the thresholds for texture, on A roads, be adjusted upwards so that T_U becomes 0.8, and T_L becomes 0.4, to reflect the results of the research and to bring the approach taken on these roads into line with the approach taken on trunk roads..

Test:

Examine the effect that the new thresholds have on the proportions of Red, Amber and Green at the network level for the different cases.

Result:

Figure 31 shows the effect of raising the texture depth thresholds on A roads. This change increases the proportion of the network is classed as Red and Amber. Although this change increases the length of the network requiring investigation, it does bring a potential safety benefit. Furthermore, the increase in length requiring investigation as a result of this change is likely to be compensated for by other alterations to the model, which have reduced the length requiring investigation without compromising safety.

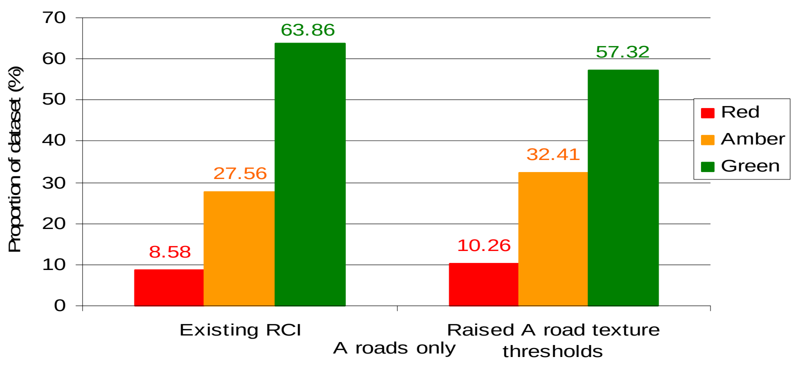


Figure 31: Effect of changing texture thresholds on A roads

Recommendation:

Adjust the thresholds used for A roads to better reflect the measure of texture on these roads

3.2.14 The relative influence of Texture

Observation:

The RCI currently uses the same thresholds and weightings for texture data on all classes and environments of road. This appears to give a disproportionate effect on some classes of road.

Specialised surfacings are often used in urban areas which provide high friction, but have (intentionally) low macrotexture depths. Such surfacings are often found in the approach to junctions, traffic lights, or bends. The low texture depths on such areas of the network result in high RCI scores even though there is in reality nothing wrong with the texture of the road surface.

Evidence:

It can be seen in Figure 7, Figure 8 and Figure 9 that, in the sample dataset of 16 Local Authorities, texture contributes to the RCI over proportionately more of the B and C road network than on A roads. This can also be seen in Figure 32, below.

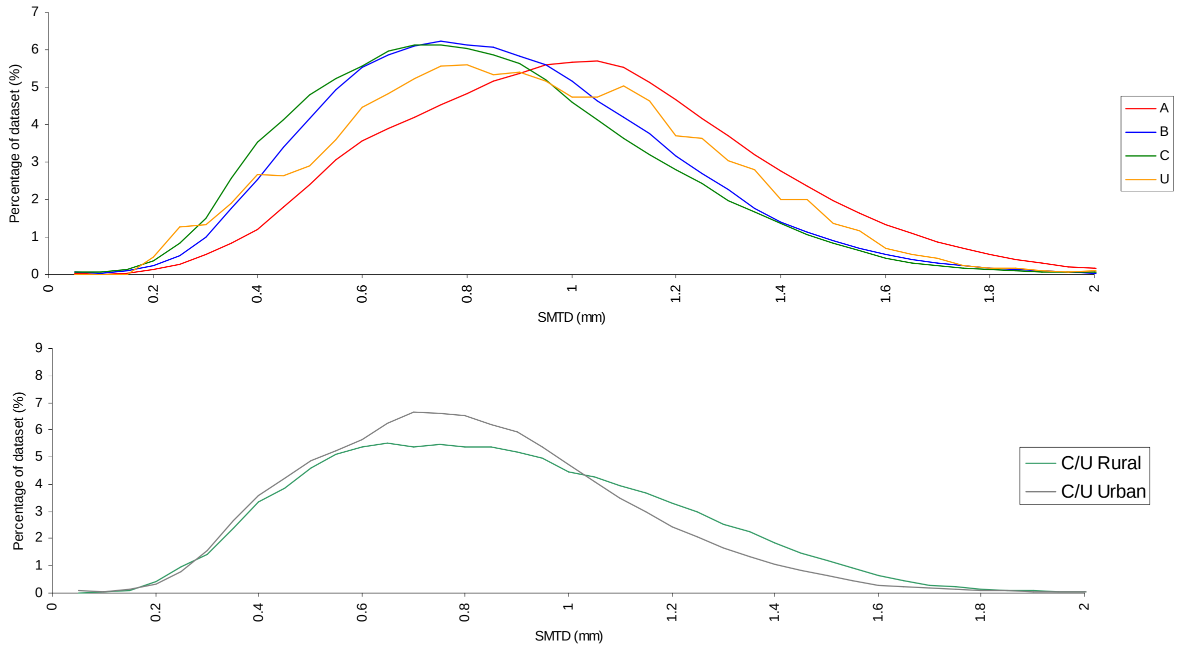


Figure 32: Distribution of texture depth on TRL test dataset, shown for A, B, C and U roads (top plot) and for minor roads in Rural or Urban environments (bottom plot).

The implications of this are that significant lengths of B, C and U roads do not meet the texture requirements, and that there is an expectation to maintain these roads to the same level of texture depth as the higher road class. Feedback from engineers suggested that highlighting a higher proportion of the C roads network for texture defects than the A road network was not appropriate.

Whereas it is true that texture is an important parameter, it is more significant in areas where loss of high speed skid resistance would be a problem. The thresholds established for texture depth assist in identifying locations where this could be the case, and this has stimulated the recommendation in section 3.2.13 to raise the thresholds for A roads. However the significance may be greater on A and B roads than on minor roads (although some of these will carry some high speed traffic), and may be much less significant on urban minor roads (where speeds are likely to be low). Such an approach is not perfect, but road class and environment are the only pieces of information regarding the road, and the likely importance of texture depth on it, which are readily available.

Proposed Action:

Initially it would seem appropriate to lowering the thresholds for C and U roads. However, given the accuracy of SCANNER, this would lead to levels that lie very close to the measurement limits of the survey machines, and would result in a lot of noise in the data. It is therefore proposed that the weightings for road classes be amended to reflect the relative significance at which the engineers view texture on different road classes.

A and B roads	=	maximum weighting of 0.75;
Rural C and U roads	=	maximum weighting of 0.5;
Urban C and U roads	=	maximum weighting of 0.3.

Test:

Examine the effect which the new weightings have on the proportions of Red, Amber and Green at the network level for the different cases.

Result:

Figure 33 compares the proportions of the TRL test dataset classed as Red Amber and Green by the current RCI and those reported by the modified RCI (which uses different weightings for the texture data depending on the road class and environment). It can be seen that, on A and B roads, where the influence of texture has been increased, there are slightly more Red and Amber lengths. On Minor Rural roads, where the influence of texture has not been changed, the model has stayed the same, and the proportions of Red, Amber and Green are identical to those from the existing model. On Minor Urban roads, where the weighting has been decreased to reflect the lower influence texture depth would have in maintenance planning, the Red and Amber proportions have decreased, and more of the roads are classed as Green.

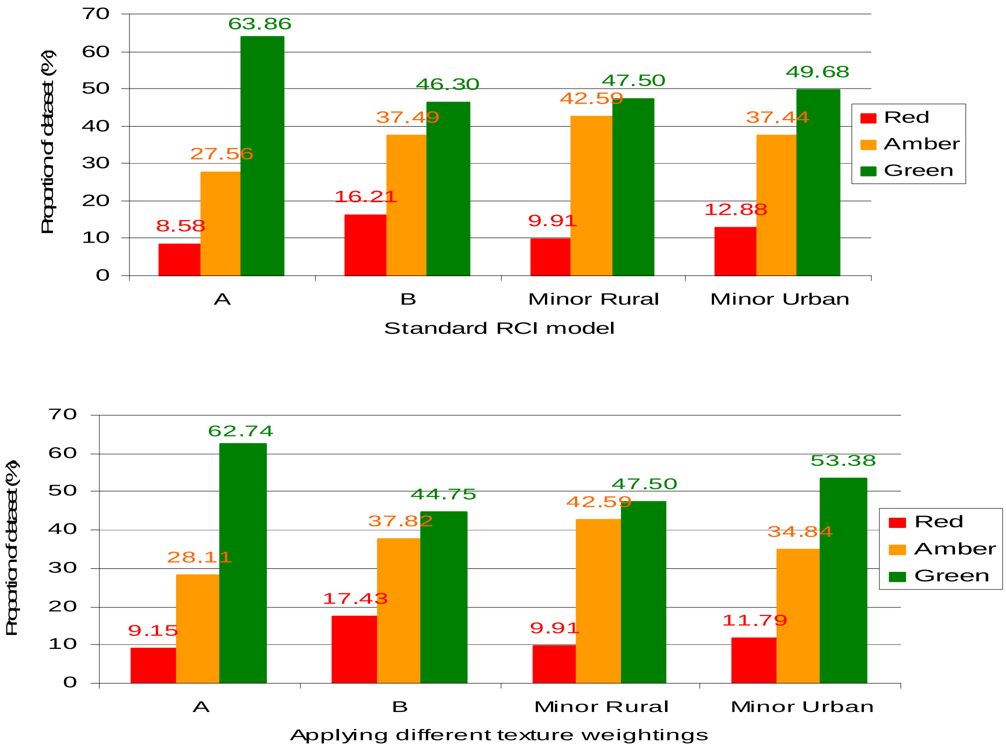


Figure 33: Proportions of dataset, split by road class and environment, within each RCI classification (Red, Amber, Green), using the existing RCI models (top), and applying different weightings to texture data depending on the class and environment of the road (bottom).

Recommendation:

Adjust the weightings given to texture depth in the calculation of the RCI, depending on the class and environment of the road.

A and B roads	=	maximum weighting of 0.75;
Rural C and U roads	=	maximum weighting of 0.5;
Urban C and U roads	=	maximum weighting of 0.3;

This modification brings the following benefits

- Raising the weighting on A and B roads will reflect the significance of texture to high speed skid resistance
- Keeping the weightings the same for rural minor roads will not change the standards to which they must be maintained. These roads may have some high speed traffic on them, but the geometry and design of the roads should make their high speed skidding resistance less of an issue than it would be on A or B roads.
- Dropping the weightings on urban minor roads will reflect the lower importance and relevance which the texture depth measurement has on these roads, which are likely to be trafficked primarily at slow speeds.

3.2.15 Effect of combined texture changes

The following alterations are proposed for the way in which the Revised RCI should include texture data:

- Raise the thresholds used on A roads to 0.8 and 0.4 to reflect the increased importance of texture on these roads;
- Change the weighting given to texture depending on the road class and type: Weight A and B roads at 0.75, Minor Rural roads at 0.5, and Minor Urban roads at 0.3.

3.2.15.1 Impact of all proposed texture changes

Figure 34 shows the proportions of the TRL test dataset having RCI values of Red, Greed and Amber using the current RCI. This can be compared with results obtained following the above modifications shown in Figure 35.

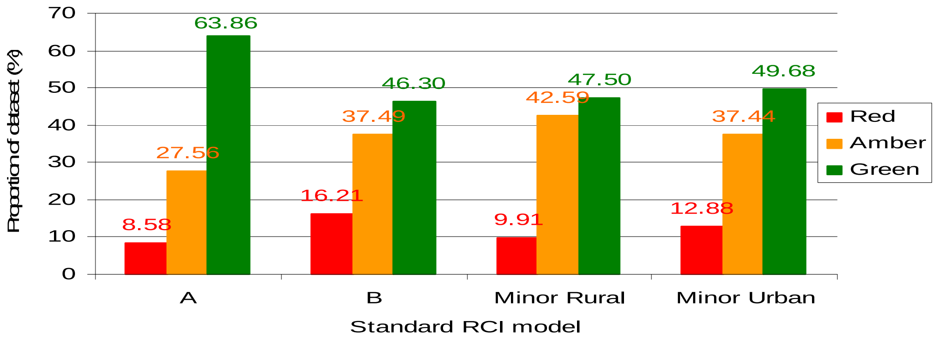


Figure 34: Network proportions of Red, Amber and Green for A, B, Minor Rural and Minor Urban roads using all existing RCI model.

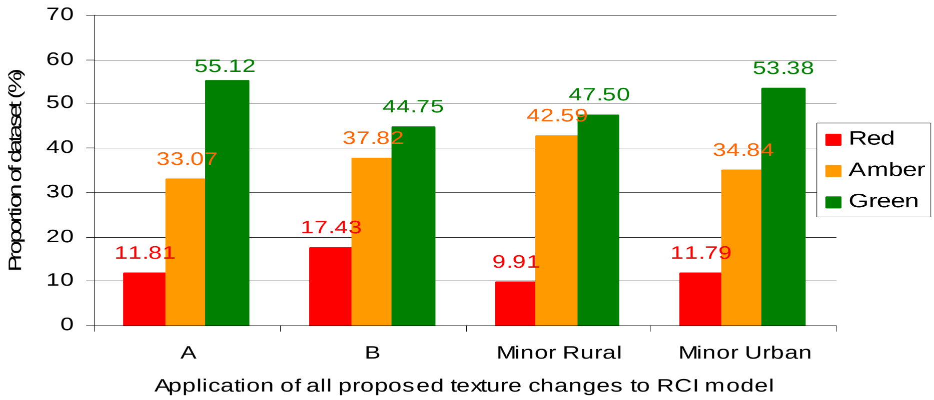


Figure 35: Network proportions of Red, Amber and Green for A, B, Minor Rural and Minor Urban roads using all proposed changes to the way in which the RCI handles texture data.

3.2.16 Summary of Findings and recommendations

The following summarises the recommendations presented in the preceding sections

- 3.2.3 – Do not change thresholds *en masse* to equalise percentiles contributing to RCI;
- 3.2.4 – Weight both LPV parameters at 0.8, and report only the higher of the two;
- 3.2.5 – Only consider road class for LPV calculations, regardless of environment;
- 3.2.6 – Use the LPV thresholds as recommended in the Shape research for B, C and U roads;
- 3.2.8– Do not remove cracking from RCI;
- 3.2.9 – Remove wheeltrack cracking from RCI, and increase weighting of carriageway cracking to 0.6;
- 3.2.10 – Allow rutting to contribute 100 points at and above T_U;
- 3.2.11 – Set rut thresholds on minor roads to be same as on A or B roads (T_L = 10, T_U = 20);
- 3.2.13 – Raise the texture thresholds on A roads from 0.6 and 0.3, to 0.8 and 0.4;
- 3.2.14 – Change weightings of texture to 0.75 on A or B roads, 0.5 on Rural C or U roads, and 0.3 on Urban C or U roads.

By combining these recommendations we obtain a revised definition for the RCI as defined in Table 26. Note that the existing maximum RCI score for any subsection of 370 for all classes and environments will change as a result of the proposed modifications. The new weightings and thresholds give a maximum score for an A or B road of 315. For a C or U class road in a rural setting the maximum is now 290, and in an urban setting 270.

	Units	Class	Defect Value T_L	Weight below T_L	Defect Value T_U	Weight above T_U	Importance	Reliability	RxI
Rutting	mm	**A, B, C, U**	10	0	20	100	1	1	1
3mLPV*	mm^2	**A**	4	0	10	100	0.8	1	0.8
		B	5	0	13	100	0.8	1	0.8
		C	7	0	17	100	0.8	1	0.8
		U	8	0	20	100	0.8	1	0.8
10mLPV*	mm^2	**A**	21	0	56	100	0.8	1	0.8
		B	27	0	71	100	0.8	1	0.8
		C	35	0	93	100	0.8	1	0.8
		U	41	0	110	100	0.8	1	0.8
Whole carriageway cracking	%	**A, B, C, U**	0.15	0	2	100	1	0.6	0.6
Texture	mm	**A**	0.4	100	0.8	0	0.75	1	0.75
		B	0.3	100	0.6	0	0.75	1	0.75
		C, U (urb)	0.3	100	0.6	0	0.3	1	0.3
		C, U (rur)	0.3	100	0.6	0	0.5	1	0.5

Table 26: Recommended SCANNER RCI Thresholds and weighting factors. ****Only the maximum of the 3 or 10m LPV shall be included in the RCI calculation at any given 10m subsection*.**

Table 27 shows the effect of the various proposed changes which were testable on the workshop sites. This shows that some of the changes had more effect than others, and some of the changes had unwanted effects. Table 27 also shows the results of the proposed final enhanced RCI on the workshop sites. These final values are present in Figure 36, which shows that the proposed settings for the new SCANNER RCI model result in a closer agreement with the engineers' opinions on the workshop sites.

Work-shop Site ID	Mean engineer rating	RCI with manual crack analysis	RCI with max LPV only	RCI with mean LPV only	RCI with max cracking only	RCI with max cracking only (0.6)	RCI with no WT cracking	RCI with no cracking at all	RCI with 100 point rut	Final RCI
1a	**127**	**190**	166	151	126	165	175	127	193	**148**
1b	**35**	**141**	108	95	94	136	137	128	142	**109**
2	**11**	**8**	13	13	9	9	10	3	13	**11**
3	**24**	**48**	49	35	42	47	47	44	49	**50**
4	**50**	**0**	0	0	0	0	0	0	0	**0**
5	**149**	**129**	129	129	110	118	107	81	134	**135**
6	**151**	**125**	109	96	111	115	91	94	128	**102**

Table 27: Summary of effect of changes to RCI model on Bracknell workshop sites

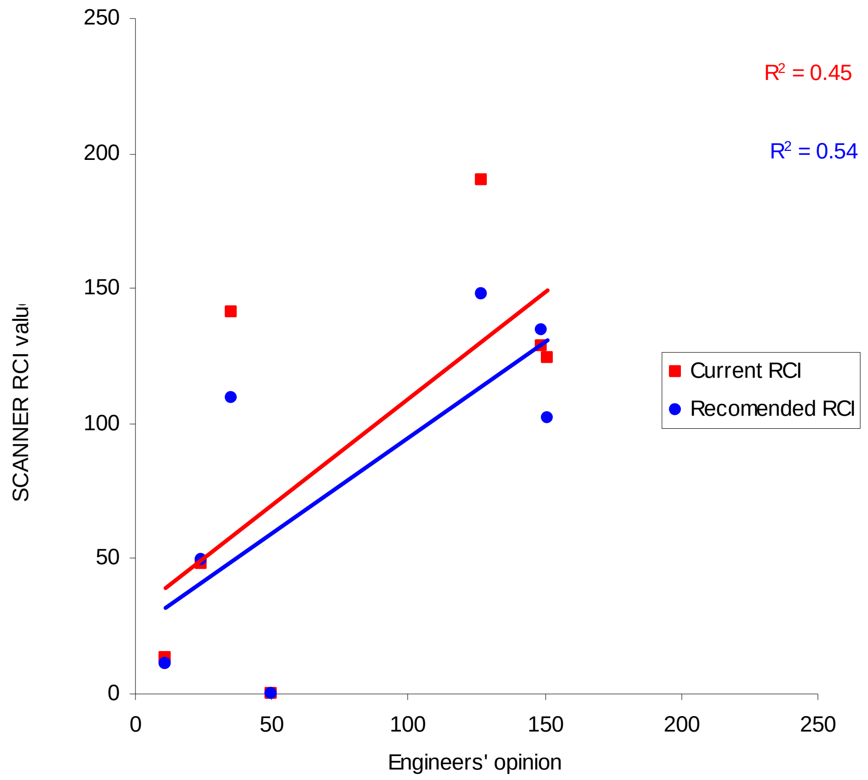


Figure 36: Relationships between average engineers' site rating, and SCANNER RCI as calculated using the current and recommended settings.

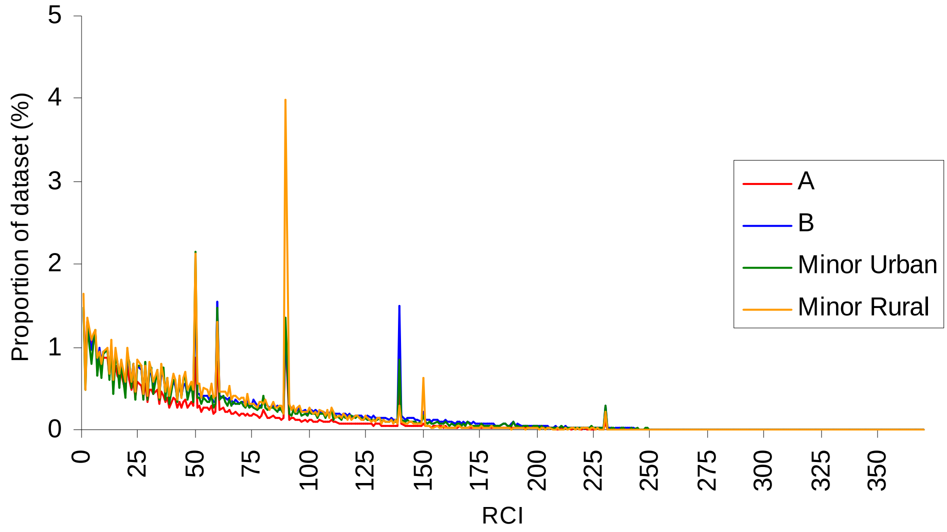


Figure 37: Distribution of RCI values for A, B C or U roads in rural and urban environments using existing RCI .

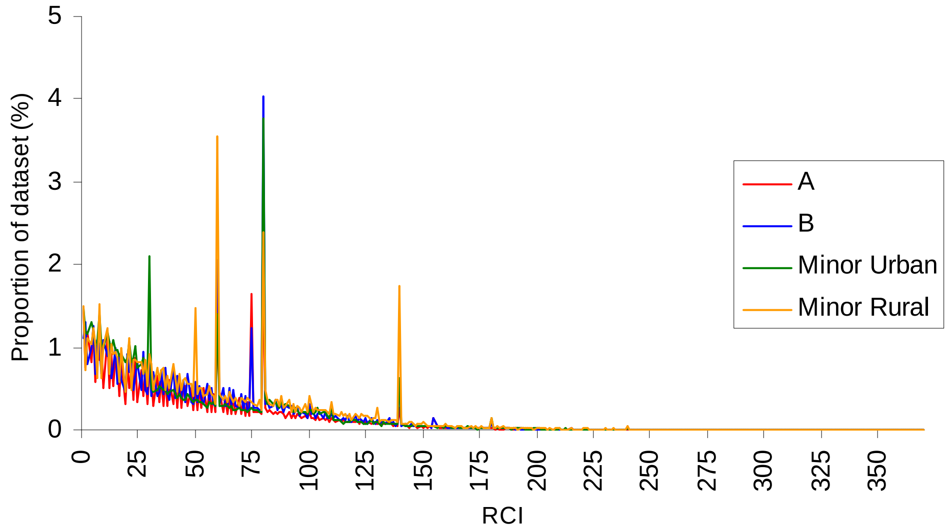


Figure 38: Distribution of RCI values for A, B C or U roads in rural and urban environments using recommended RCI .

Figure 37 and Figure 38 show the distribution of RCI values obtained using the current and proposed models. These distributions reflect of all the data in the test dataset, excluding DCL (to minimise the effect of the uncertainty over their crack data). Figure 38 shows that the distributions have not changed significantly from those obtained previously, but that new peaks have appeared in some of the distributions. For example there are now peaks at:

- 30 points in the distribution of RCI on minor urban roads, due to the lower texture weighting applied here;
- 50 points on minor rural roads, again due to texture;
- 60 points on all roads, due to carriageway cracking;

- 75 points on A and B roads, due to texture;
- 80 points on all roads, due to whichever of the two LPV parameters is contributing at that point;
- There is also a very small peak at 100 points due to the increased weighting of rutting.
- The peak which was previously seen at 90 points is no longer there. The disappearance of this peak (and the small peak at 100) suggests it was caused primarily by the double counting of the two cracking parameters (50 and 40 points for carriageway and wheeltrack cracking), than it was by the maximisation of the rut contribution (90 points).

Figure 39 and Figure 40 show that the changes to the RCI model result in lower proportions of roads classed as red. This is particularly true for B roads, due to the reduced requirements for LPV on these roads. There is also a reduction for minor urban roads, due to the lowered requirements for texture depth, and the relaxing of the LPV requirements to match those on rural roads.

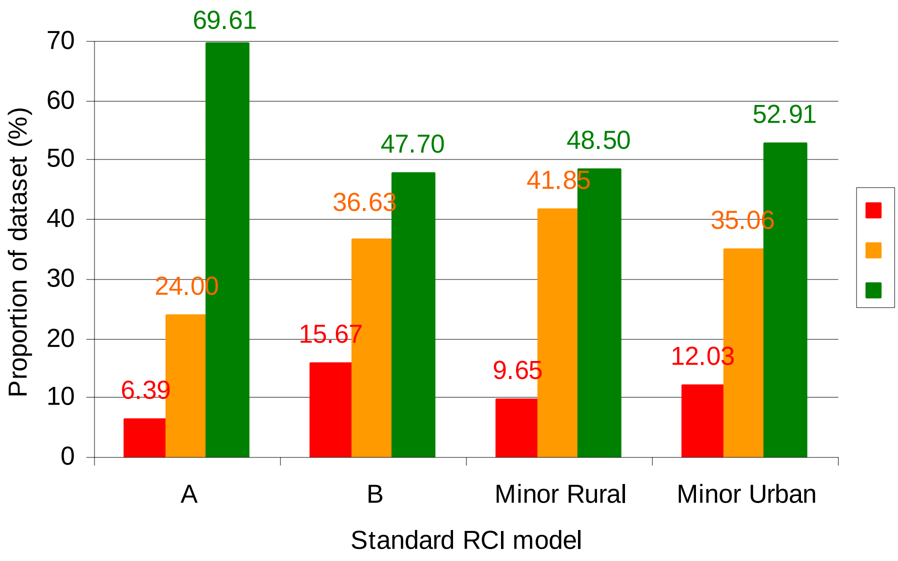


Figure 39: Proportions of data within each RCI class using current RCI model.

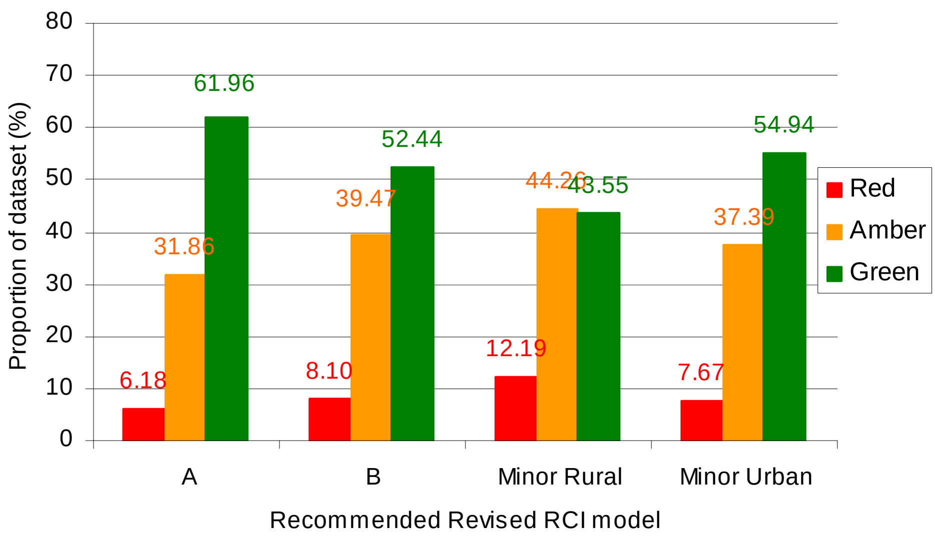


Figure 40: Proportions of data within each RCI class using recommended RCI model.

4 Effect of including a varying proportion of C roads on RCI

BV224(a) reports the condition of ‘other classified roads’ (excluding Principal roads which are reported in BV223). The requirement for surveying B roads asks for the full network of B roads to be surveyed in one direction in one year, with the other direction being surveyed the following year. In 2005/06 the calculation of an LA’s BV224(a) value was required to include at least 10% of the C roads in the LA. In 2006/07 the requirement was raised to include at least 50% of the LA’s C roads. The 50% surveyed in year 06/07 are to be different from the 10% surveyed in year 05/06, meaning that by the end of the 06/07 survey year, at least 60% of the C roads in any LA will have been surveyed and used in the calculation of the LA’s BV224(a) figure.

BV224(a) is calculated based on data collected in the previous 2 years.

In addition to the calculation of the BVPI figures, Local Authorities have been requested to calculate values for the B and C roads separately.

The BV224(a) value is calculated using the following formula:

$$\text{BV224(a)} = 100\left(\frac{\left(C_C\left(\frac{L_C}{S_C}\right)\right)+\left(C_B\left(\frac{L_B}{S_B}\right)\right)}{C_C + C_B}\right)$$

Where:

C_B or C_C = Carriageway length of B or C roads in network

L_B or L_C = Lane length of B or C roads assessed as Red

S_B or S_C = Lane length of B or C roads surveyed.

Because the requirement for C road inclusion in the BVPI calculation changes from 10% to 60% over two years, there is a concern that the BVPI will change dramatically as a result.

The key to the problem is an understanding of the BV224(a) equation. It is essentially a weighted average of two numbers: the percentage of Red B roads and the percentage of Red C roads. The higher the ratio of lengths of B:C roads there are across the county, the more the B roads will influence the overall value for example.

So, assuming:

1. that the length of the network in the county does not change substantially from 2005/06 to 2006/07;

and

2. and that the 10% sample of C roads collected in the 2005/06 period is representative,

then the percentage of Red C roads and the percentage of Red B roads is not likely to change substantially in the 2006/07 period, even if the sample of C roads is bigger (60%).

4.1 Effect of the proportion of B and C roads on the RCI

The effect of the proportion of road types on the resultant RCI can be demonstrated using a worked example. Hence, if we take a county having 856km (C_B) of B roads and 1736km (C_C) of C roads.

In 2005/06:

50% of B roads (428km = S_B) and 10% of C roads (174km = S_C) were surveyed.

7.9% of the B roads surveyed were classed as red (0.079*428 = 34km = L_B).

9.0% of the C roads surveyed were classed as red (0.09*174 = 16km = L_C).

$$BV224(a)_{05/06} = 100\left(\frac{\left(1736\left(\frac{16}{174}\right)\right)+\left(856\left(\frac{34}{428}\right)\right)}{1736+856}\right)$$

$BV224(a)_{2005/06} = 8.6$

If points **1** and **2** above are valid, then the second year's survey, with an additional 50% of B and C roads, in the period 2006/07, results in the following figures for 2006/07:

S_B = 856km, S_C = 1041km.

7.9% of the B roads surveyed were classed as red (0.079*856 = 68km = L_B).

9.0% of the C roads surveyed were classed as red (0.09*1041 = 94km = L_C).

$$BV224(a)_{06/07} = 100\left(\frac{\left(1736\left(\frac{94}{1041}\right)\right)+\left(856\left(\frac{68}{856}\right)\right)}{1736+856}\right)$$

$BV224(a)_{2006/07} = 8.6$

This, of course, assumes that the quality of the roads surveyed will not change in 2006/07. However, it has been proposed that the 10% of C roads selected for survey in 2005/06 may have been the chosen because it was relatively easier 10% to survey, perhaps containing the wider, straighter C roads. This in turn, may lead to them being more important to the local transport system, making them higher priorities for maintenance. However, their condition may therefore be unrepresentative of the C road network as a whole. There are no survey data, or BVPI results, to show this is the case, but discussions with engineers and survey providers have tended to give credence to the hypothesis.

If the initial 10% of C roads surveyed in each network were unrepresentatively good, then it follows that the next 50% would be in a worse condition, and would include more Red lengths. The effect which this may have on the BVPI has been investigated using the following assumptions and data:

A selection of 17 LAs with BVPI results for 2005/06 for B and C roads are shown in Table 28. The length of the B and C networks, and the percentage of Red roads in the surveyed network are shown in columns 2 – 5 (C_B, C_C, L_B/S_B and L_C/S_C).

The BVPI result for 2005/06 is shown, and a simulated BVPI result for 2006/07 is calculated using the following assumptions:

1. total county road length remains the same for B and C roads (C_B and C_C);
2. the surveyed length increases to 100% for B (S_B) roads and 60% for C (S_C) roads;
3. the percentage of Red B roads (L_B) is unchanged from 2005/06.
4. the percentage of Red C roads (L_C) doubles from 2005/06.

Column 7 (2006/07 BVPI sim) shows that an increase in the proportion of Red C roads in the surveyed sample increases the BVPI. This increase is not exactly proportional to the level of increase in the amount of red lengths surveyed (which doubles) because the result depends on B roads as well.

The final column in Table 28 states the ratio of the BV224(a) values from 2006/07 to those from 2005/06 given a doubling of the percentage of Red C roads. This ranges from 1.3 to 1.9 depending on the relative lengths of B and C roads in the county and the difference between the qualities of B and C roads.

LA	C_B	C_C	L_B/S_B	L_C/S_C	2005/06 BVPI	2006/07 BVPI sim	Ratio
Bedfordshire	221	1068	6.3	6.0	6.0	11.0	1.8
Warwickshire	856	1736	7.9	9.0	8.6	14.7	1.7
Nottinghamshire	568	1538	8.9	8.0	8.2	14.1	1.7
Lincolnshire	1569	5834	10.2	4.4	5.6	9.1	1.6
Poole	62	53	11.0	6.2	8.8	11.6	1.3
Devon	1338	9021	12.1	7.1	7.7	13.9	1.8
Wokingham	117	171	13.6	8.4	10.5	15.5	1.5
Buckinghamshire	295	1841	13.7	10.8	11.2	20.5	1.8
North Somerset	165	497	14.1	10.6	11.5	19.4	1.7
North Yorkshire	1319	5497	14.7	6.0	7.7	12.5	1.6
Essex	1504	3228	16.0	19.0	18.0	31.0	1.7
Haringey	39	43	16.0	8.0	11.8	16.0	1.4
Somerset	914	4437	16.1	4.7	6.6	10.5	1.6
Cambridgeshire	1120	2160	17.5	11.1	13.3	20.6	1.6
Bath & N E Somerset (BANES)	96	628	20.0	22.9	22.5	42.4	1.9
Cumbria	1160	4636	26.0	14.0	16.4	27.6	1.7

Table 28: BVPI results for 2005/06 and simulated for 2006/07

4.2 Obtaining confidence in the reported RCI value

When assessing the effects of changing the proportions of different road classes on the RCI it is appropriate to consider what the requirements for the survey data may be in order to be confident (e.g. 95% certain) that the resulting report of how much Red was in the network was accurate, within certain defined error bounds. To perform this task we have selected a random sample of 5000 10m subsections of C roads from within the TRL 16 LA dataset, and used this to create a hypothetical LA with 50km of C roads.

4.2.1 Results

12.4% of the 5000 data points in the hypothetical C road network were Red, according to the existing RCI. Figure 41 shows the relationship between the proportion of the population sampled (x-axis) and how confident we could be about the estimate from that sample (y-axis). The confidence interval value is calculated from the general form of a confidence interval: $\pm z\sigma$, which for proportions uses the standard error of proportions σ_p:

$$\sigma_p = \frac{p(1-p)}{N}$$

where p is 12.4% in this case, and N is the size of the sample. Z for all the calculations here is 1.96 to determine a 2 sided 95% confidence interval.

The confidence interval around the mean (displayed on the y-axis of Figure 41) represents the distance from the population proportion (mean) to the edge of the 95% confidence interval. For example, a 20% sample (1000 x 10m lengths) gives a confidence interval of 2.0%. Hence, there is 95% confidence that the proportion of Red C roads calculated using this 20% sample lies within 2.0% of the true proportion of Red roads in the whole 50km network (i.e. between 10.4% and 14.4%). We can extend this example to show the range of confidence limits obtained for increasing randomly surveyed lengths of this 50km network (with 12.4% red), as shown in Table 29.

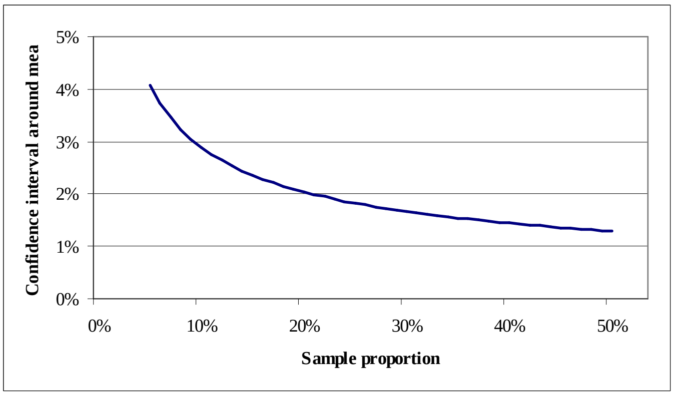


Figure 41: Random sample proportion required to reach confidence intervals around 12.4% red roads in 50km.

Proportion of the network surveyed	Lower confidence limit	Upper confidence limit
5%	8.31%	16.49%
10%	9.51%	15.29%
15%	10.04%	14.76%
20%	10.36%	14.44%
25%	10.57%	14.23%
30%	10.73%	14.07%
35%	10.86%	13.94%
40%	10.96%	13.84%
45%	11.04%	13.76%
50%	11.11%	13.69%

Table 29: Confidence intervals around 12.4% red roads in 50km for selected sample proportions.

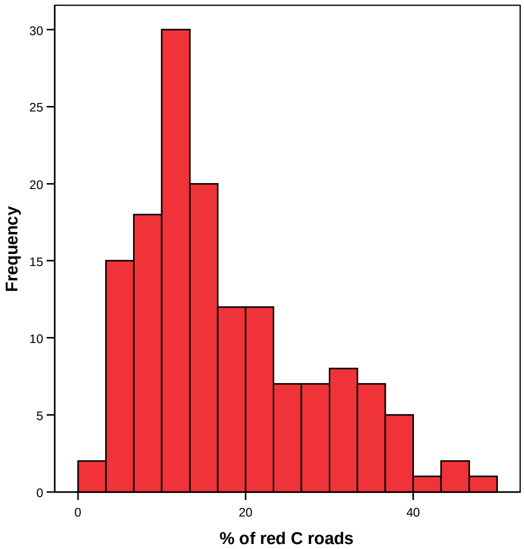


Figure 42: Distribution of BV224(a) values

We can generalise the above investigation to determine how the condition of the network (the proportion of Red lengths) influences the 95% confidence interval. Because the calculation involved in determining the confidence limits depends on the population size and the network condition, this may be achieved by developing a series of scenarios based on the distribution of C road lengths for all Local Authorities, and the RCI values obtained for B and C roads in these Authorities (Figure 42).

Figure 43 shows the relationship between the proportion of the network surveyed (x-axis) and the distance between the population proportion of red roads and the edge of the confidence interval (y-axis) for five different networks having a range of proportions of red roads, each with a network length of 50km. It should be noted that this method assumes that the network surveyed is selected randomly. Hence, if a quarter of the network is randomly surveyed, the 95% confidence interval is between 1.2% points (for 5% red roads) and 2.7% points (for 40% red roads). That is, there would be a 95% probability of the true %red value lying within ± 1.2% points of the reported % red value (for a network with 5% red roads) or within ±2.7% points (for 40% red roads).

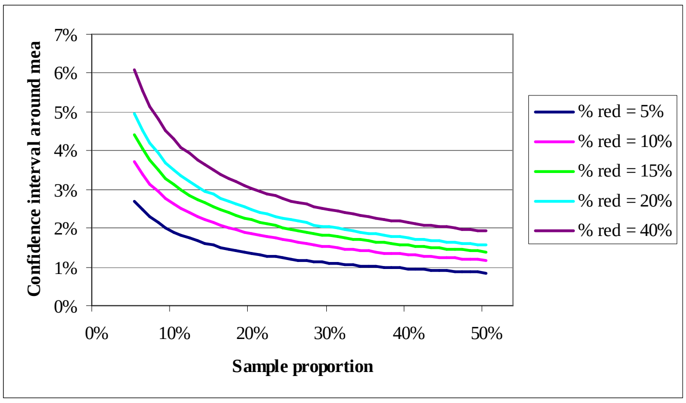


Figure 43: Random sample proportion required to reach confidence intervals around 5, 10, 15, 20 and 40% red roads in 50km networks.

We now vary the network length, maintaining the range of red lengths. It is clear from the following figures that the shapes of the relationships are the same for different network lengths. However note that the scales are not the same. The plots are not designed to have comparisons drawn between them.

- Figure 44 shows the relationships for 200km networks. If a quarter of the network is randomly surveyed then the 95% confidence interval around the population proportion is between ±0.6% points (for 5% red roads) and ±1.3% points (for 40% red roads).
- Figure 45 shows relationships for 400km networks. If a quarter of the network is randomly surveyed then the 95% confidence interval around the population proportion is between ±0.4% points (for 5% red roads) and ±0.9% points (for 40% red roads).

Towards the larger network sizes the confidence interval around the actual population proportion of red roads decreases to a population proportion ± <1% if the randomly surveyed proportion of network is 10% or bigger. This implies that if the sample randomly surveyed is characteristic of the whole network then the confidence interval around the estimate is small and the accuracy good.

- Figure 46 shows relationships for 1000km networks. If a quarter of the network is randomly surveyed then the 95% confidence interval around the population proportion is between ±0.3% points (for 5% red roads) and ±0.6% points (for 40% red roads).
- Figure 47 shows relationships for 2000km networks. If a quarter of the network is randomly surveyed then the 95% confidence interval around the population proportion is between ±0.2% points (for 5% red roads) and ±0.4% points (for 40% red roads).

By considering these examples we are able to propose a range of potential survey lengths that would be required in order to obtain a specific confidence in the reported RCI. Hence to obtain an RCI with 95% confidence that the obtained RCI lies within ±0.75 of the true RCI would require the following (approximate) randomly surveyed lengths:

- For a 50km network: 100% survey, or 50km
- For a 200km network: 50% survey, or 100km
- For a 400km network: 30% survey, or 120km
- For a 1000km network: 15% survey, or 150km

- For a 2000km network: 10% survey, or 200km

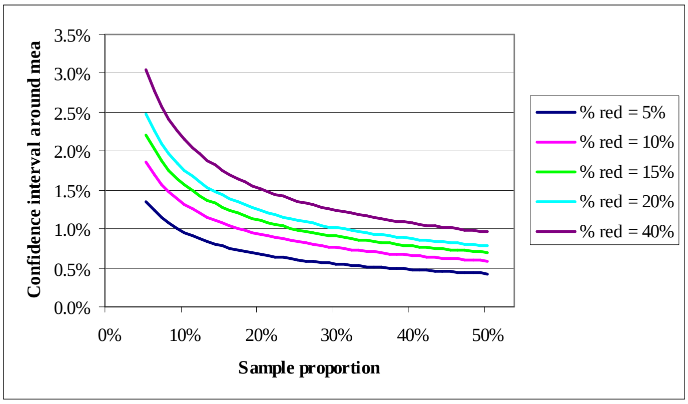


Figure 44: Random sample proportion required to reach specified confidence intervals, 200km network.

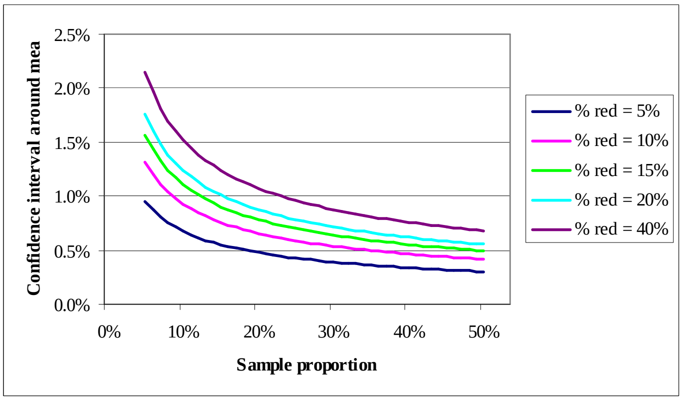


Figure 45: Random sample proportion required to reach specified confidence intervals, 400km network.

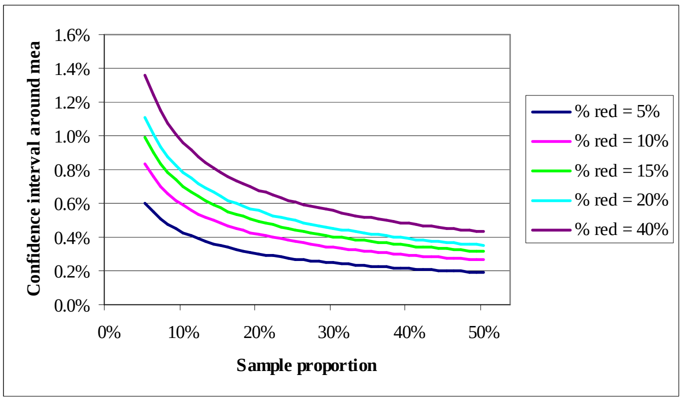


Figure 46: Random sample proportion required to reach specified confidence intervals, 1000km network.

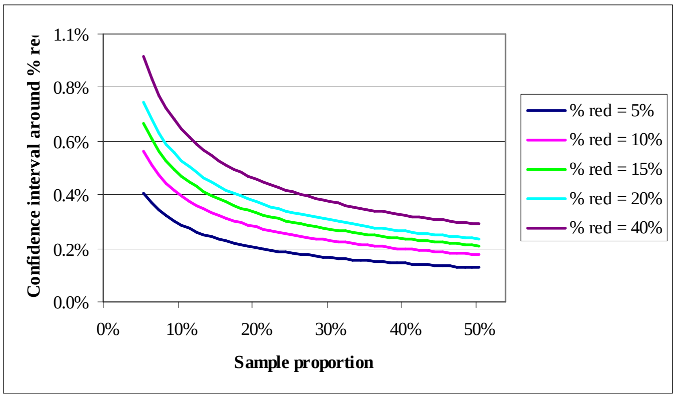


Figure 47: Random sample proportion required to reach specified confidence intervals, 2000km network.

5 Benchmarking

One of the key objectives of this work was to compare the SCANNER RCI values obtained in different types of local authority in order to establish benchmarks for groups of authorities. This has been approached in three ways, which are discussed below: firstly, an initial investigation has been carried out to determine which factors are statistically significant in explaining differences in the RCI % red and, subsequently, two alternative methods of grouping authorities have been explored.

All these investigations were implemented using the 2005/06 RCI results for local authorities in England. The results therefore relate to the percentage of each authority's network that is classified as red using the current RCI definition. Local Authorities that employ DCL as their survey contractor have been removed from the analysis.

5.1 Initial investigation

In an initial investigation, a General Linear Model was fitted to the data for each of two outcome variables and for each of two sets of explanatory variables. This process therefore determines, on a statistical basis, which of the explanatory variables affect the RCI value when reported as percentage red (for A or B/C roads).

Outcome variables:

1. RCI expressed as percentage red - A roads
2. RCI expressed as percentage red - B and C roads

Explanatory variables (Set 1):

- Survey contractor
- Region
- Authority type
- % built-up roads
- Length of network
- Percentage of network that is A roads
- Percentage of network that is B roads
- Percentage of network that is C roads

Explanatory variables (Set 2):

- Survey contractor
- Region
- Authority type
- Length of network
- Percentage of network that is built-up A roads
- Percentage of network that is built-up B roads
- Percentage of network that is built-up C roads
- Percentage of network that is non-built-up A roads
- Percentage of network that is non-built-up B roads
- Percentage of network that is non-built-up C roads

Note that some explanatory variables are absent from the lists, for example percentage U roads and percentage non-built-up, as these are values that can be calculated from other variables in the model, and therefore are not independent. The model removes variables by a manual stepwise procedure if the significance is greater than 5%, or the variance inflation factor is more than 10. The variables that remain are classed as significant in determining differences between local authorities of differing RCI values.

For outcome 1 (percent red A roads) and explanatory variables set 1, the variables of importance in distinguishing across RCI values are region and percentage of built-up roads. From pairwise comparisons between regions it is clear that London has significantly different RCI values, on average, than most other regions. The model also suggests that the more built up the road network is, the higher the RCI score. The adjusted R^2 (measure of goodness of fit – i.e. proportion of outcome variability explained by the model) is 0.37.

Figure 48 shows the distributions of RCI score across the different categories predicted by model 1, i.e. by region and the percentage of built up roads. For the purposes of grouping, percentage of built-up roads has been split at 75%, which is the mean level. Authorities with 75% or less of built-up roads form one set of categories, and authorities with more than 75% of built-up roads form another set of categories. Within the box plot each box represents one group with the centre line representing the median value, the upper end of the box depicting the upper quartile value (75th percentile), the lower end of the box showing the lower quartile (25th percentile) and the outer extremes showing maximum and minimum values. Statistical outliers are shown as circles or stars. With 16 subgroups, the numbers within each group are small and some only contain one LA, for example, North West >75% BU and West Midlands >75% BU.

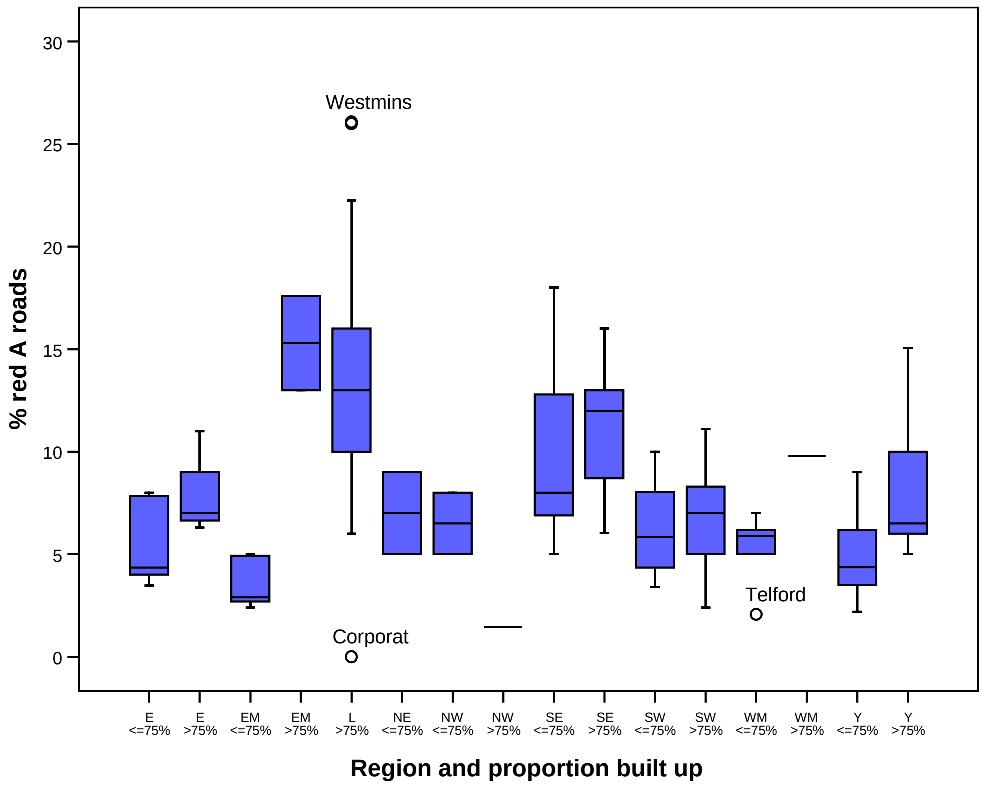


Figure 48: Box plot of percentage red A roads split by region and percentage of built-up roads

Using set of explanatory variables set 2, the important variables are percentage of built-up A roads and percentage of built-up B roads. A higher adjusted R^2 value of 0.48 suggests this model explains more of the variance in the percentage red RCI A roads than the first model. An increase in the percentage of built up A roads and built up B roads increases the RCI percentage red A roads value according to the model. A relatively consistent message from the two models suggests that the percentage of the network that is built up is an important variable in explaining RCI percentage red for A roads. Similarly for B and C roads: within explanatory variables set 1, the percentage of built up roads, percentage of A roads and percentage of B roads are important for explaining the RCI percentage red. For explanatory variables set 2, the percentage of built up B roads is important. However, the reduced adjusted R^2 values are low (0.16 and 0.22 respectively), indicating that this model is less successful in explaining differences between authorities.

It should be noted that this analysis has taken the approach of considering the known variables to determine statistically how well these variables account for the different in RCI percentage red value across different LAs, using the measured RCI as the basis to identifying the explanatory variables. This approach has suggest that the percentage of built-up roads may influence the result (on A roads), but this is not necessarily a practical way of separating LA's, and there are additional explanatory factors having a lower level of influence. An alternative approach is to attempt to identify subgroups of authorities, through judgement (independently of the RCI value), and then assess the success of these subgroups, as discussed in the following section.

5.2 Subgroups based on expert judgement

The authorities were separated into 16 subgroups using a process of judgement, which suggested groups based on on authority type and proportion of urban roads on their network. Figure 49 and Figure 50 display the results of these groupings in terms of the ranges of RCIs obtained within each group. Again, in some cases, the groups do not contain many authorities. This process did not highlight distinct groups, but it was apparent that London Borough Council groups and Central London groups for B&C roads had higher RCIs. This lead to the consideration of further possible groupings based on authority type, as displayed in Figure 51 and Figure 52.

Figure 51 shows the authority type split for A roads. It is clear that London Boroughs have higher percentage red values, and there is a greater range of results within the London Boroughs and Unitary Authorities than within Metropolitan Districts and Councils. However there is little difference in the distribution of percentage red A roads in Unitary Authorities, Councils and Metropolitan Districts. Even less differentiation is visible in Figure 52 for percentage B&C roads.

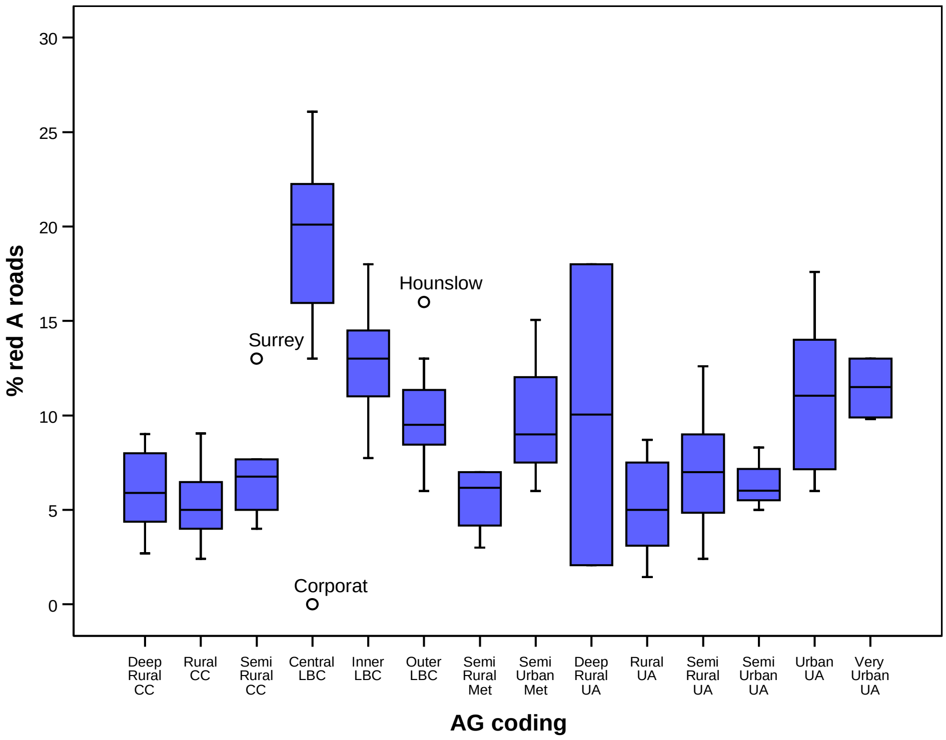


Figure 49: Subgroups for A roads

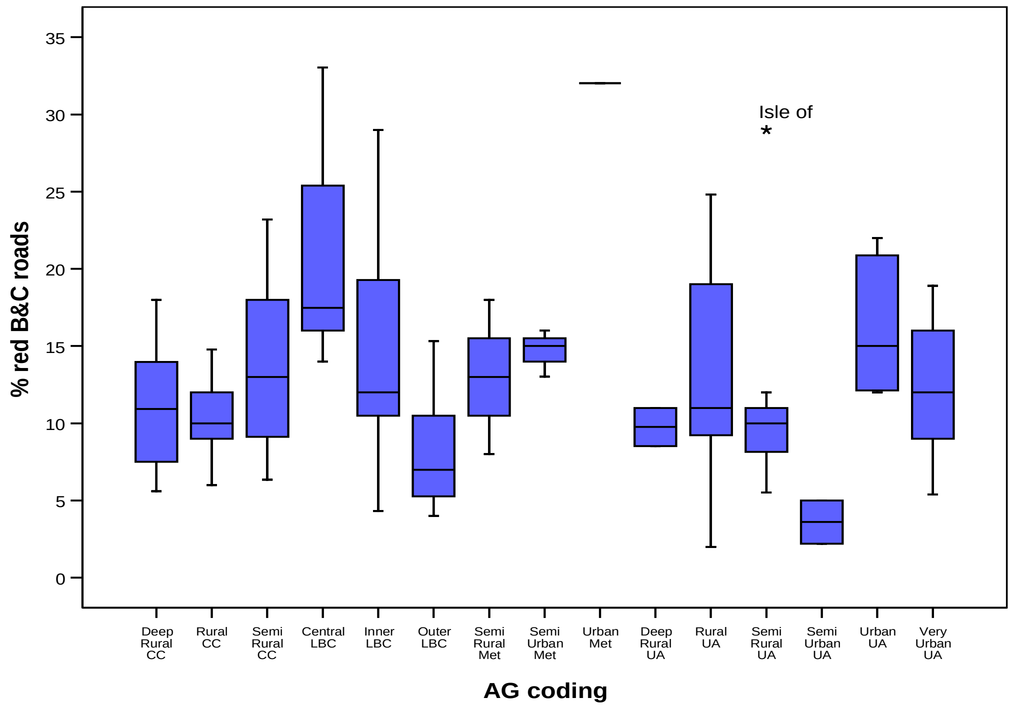


Figure 50: Subgroups for B&C roads

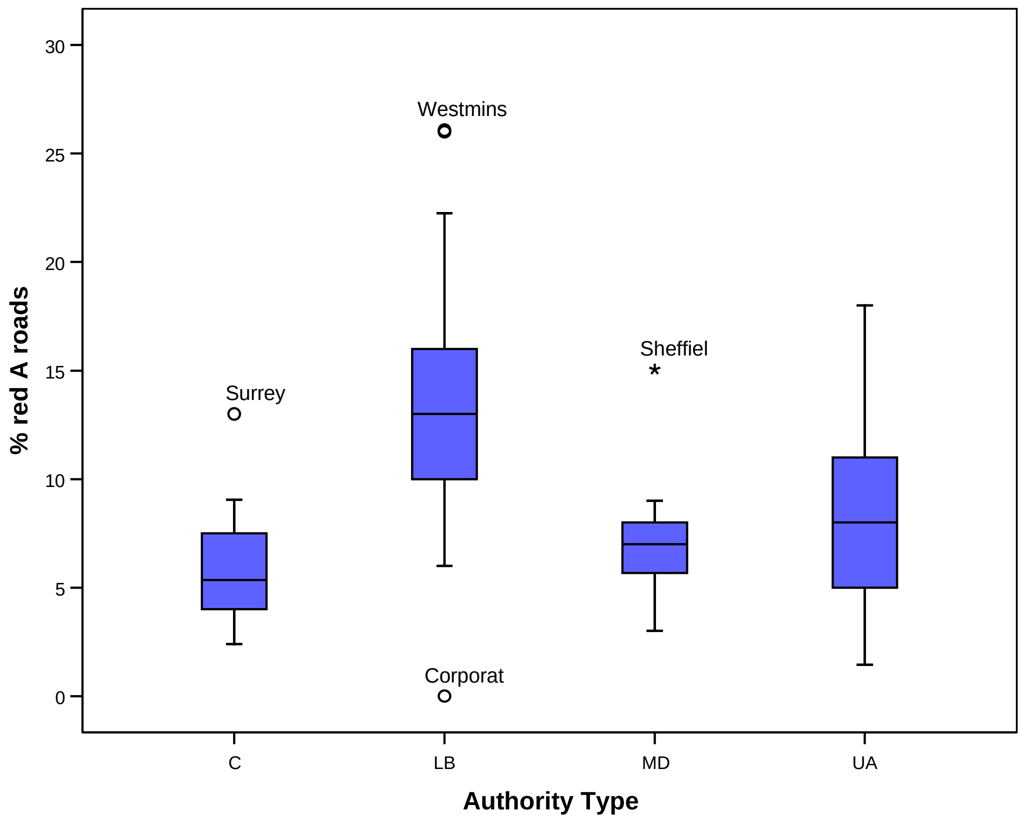


Figure 51: Authority type split for A roads

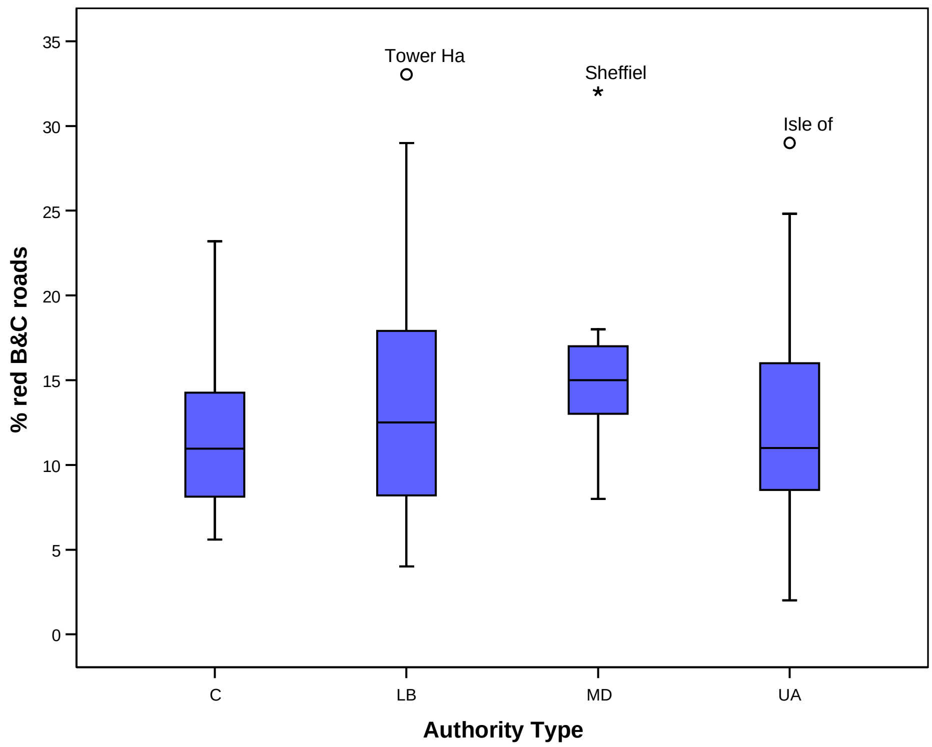


Figure 52: Authority type split for B&C roads

5.3 Subgroups based on cluster analysis

Cluster analysis was also applied to divide the authorities into similar groups (similar defined using the variables selected – type, length of network, region, % A, % B, % built up etc), without taking account of RCI values. A two step clustering technique was implemented to determine groups of local authorities having similar characteristics. Clustering identifies a set of groups which minimize within-group variance and maximise between-group variance. The method handles categorical data (e.g. authority type) and continuous data (e.g. percentage A roads) and automatically selects the optimal number of clusters using Akaike Information Criteria or Bayesian Information Criteria (which are measures of how well the model fits the data). A log-likelihood measure determines the clusters by attributing probability distributions to the variables.

All explanatory variables were entered into the model and the results revealed three clusters. A mixture of variables defines the clusters, but broadly:

- Cluster 1 contains authorities in London.
- Cluster 2 is determined primarily by the variables authority type and length of network, containing all Metropolitan Districts and short network Unitary Authorities.
- Cluster 3 contains County Councils and longer networked Unitary Authorities.

Other variables are important in determining the clusters - percentage C roads, percentage U roads, percentage non built-up, percentage built-up and combinations of these variables all contribute substantially to the discrimination between clusters.

Table 30 shows the authorities contained in each cluster. Figure 53 and Figure 54 show the distributions of percentage red roads obtained for each cluster. A difference in medians is obvious for percentage red A roads in Figure 53, with cluster 1, containing London, having the highest median (13%), cluster 2, containing Metropolitan Boroughs and short network Unitary Authorities, has the next highest median (8%) and cluster 3 has the lowest median (5%), for long network Unitary Authorities and County Councils. Figure 54 shows that B&C roads are not discriminated well, as has been seen throughout the investigation.

1	2	3
Barking & Dagenham	Barnsley	Bedfordshire
Barnet	Bath and NE Somerset	Buckinghamshire
Bexley	Bournemouth	Cambridgeshire
Brent	Bracknell Forest	Cornwall
Bromley	Bristol	Cumbria
Camden	Calderdale	Devon
Corporation of London	Doncaster	Dorset
Croydon	Halton	Durham
Ealing	Isle of Wight	East Riding of Yorkshire
Enfield	Kingston-upon-Hull	Essex
Greenwich	Leeds	Hertfordshire
Hackney	Leicester	Kent
Hammersmith & Fulham	Luton	Lancashire
Haringey	Medway	Leicestershire
Harrow	North East Lincolnshire	Lincolnshire
Havering	North Somerset	Norfolk
Hillingdon	Nottingham	North Lincolnshire
Hounslow	Peterborough	North Yorkshire
Islington	Plymouth	Northamptonshire
Kensington & Chelsea	Poole	Northumberland
Kingston-upon-Thames	Portsmouth	Nottinghamshire
Lambeth	Reading	Oxfordshire
Lewisham	Rotherham	Rutland
Merton	Sheffield	Shropshire
Newham	Slough	Somerset
Redbridge	South Gloucestershire	Staffordshire
Richmond upon Thames	Southend-on-sea	Suffolk
Southwark	Stoke-on-Trent	Surrey
Sutton	Swindon	Warwickshire
Tower Hamlets	Telford & Wrekin	West Berkshire
Waltham Forest	Thurrock	Wiltshire
Wandsworth	Torbay	Worcestershire
Westminster	Wakefield	
	Windsor & Maidenhead	
	Wokingham	
	York	

Table 30: Cluster contents

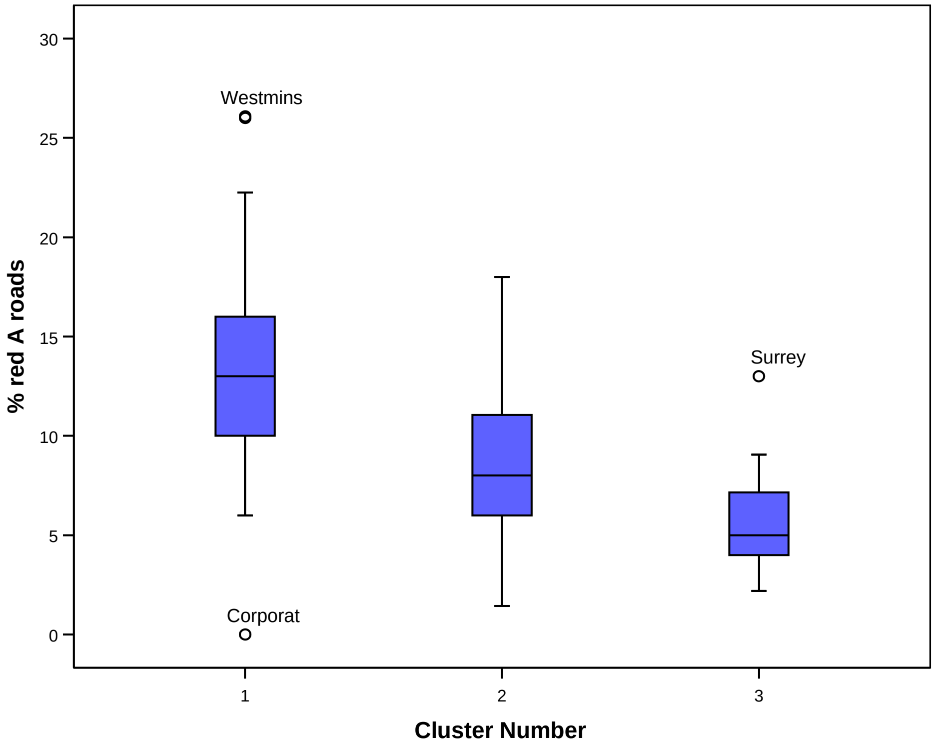


Figure 53: Cluster split for A roads

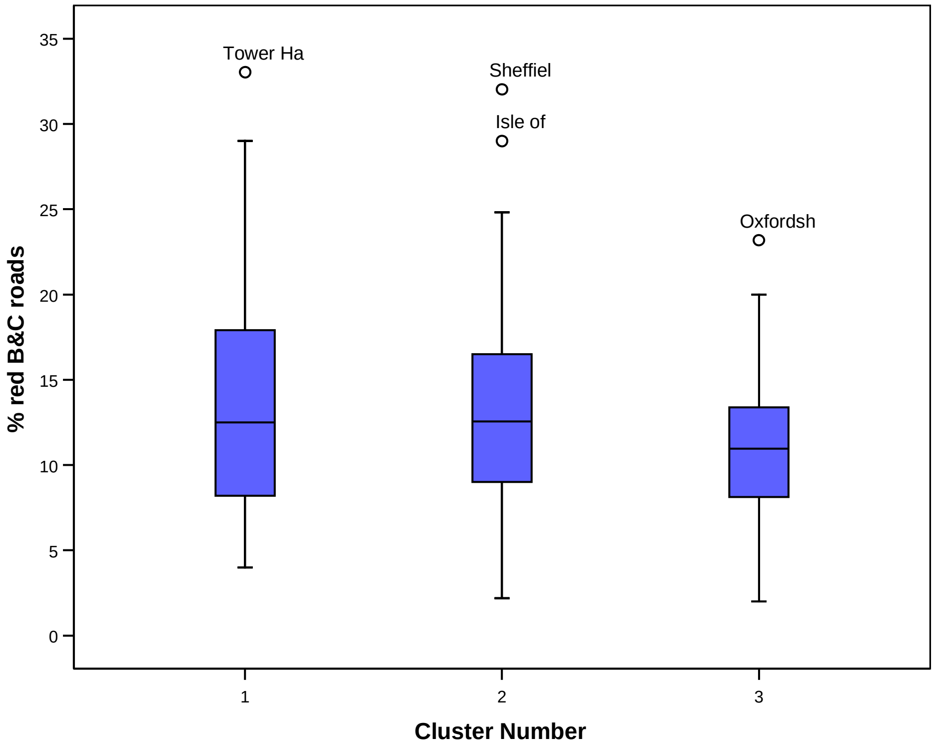


Figure 54: Cluster split for B&C roads

5.4 Summary

As suggested by the initial analysis, no subgroups that have been defined above are ideal at differentiating groups of authorities with differing RCI percentage red values, especially for B&C roads. This is due to too much variation in the data that cannot be explained by the explanatory variables that are available. It is possible that there may be other variables (countable or not) that categorise the authorities better, for example budget or priority on road spending within the authority, that are not accessible within the scope of this work.

In summary, the most robust method discussed above for classifying local authorities is the clustering technique, and from this there are visible differences in medians between the groups for percentage red A roads. However, it should be noted that there remains a large range in the percentage red for A roads for different authorities within these clusters, which limits the usefulness of this technique for establishing benchmarks. It has not been possible to classify authorities into clusters that distinguish different percentage red for B&C roads.

6 Trajectories

The main objective of the trajectories element of the project was to develop a simple model that would project the RCI for a given network over a period of 5 years under different maintenance strategies. The inputs to the model would be an initial (current year) distribution of RCI values for the authority, proposed maintenance lengths and the efficiency related to the maintenance. This tool will assist local authorities to determine an appropriate RCI target by enabling them to explore the possible consequences of different maintenance strategies on the condition of their network.

6.1 Methodology

There are two main elements to the trajectory methodology, these are: projecting the deterioration of RCI values over time; and applying the proposed maintenance to improve network condition. In order to simplify the trajectory method, the model was based on the distribution of 10m RCI values, i.e. the number of times each RCI value was reported on the network in the initial year. The distribution of RCI values referred to here and throughout this section is the distribution of RCI values obtained from the individual 10m lengths of road (such as shown in Figure 2), as opposed to the percentage of the distribution that is classified as red which was considered in the previous section. This meant that the user would not need access to the vast amounts of condition data from which the RCI is calculated, so the model could be developed in a simple spreadsheet that could be readily distributed and would require minimal processing time.

Clearly, the simplicity of this approach means that the reliability of the results must be investigated. A simple sensitivity analysis to explore the behaviour of the trajectory model is described within this section.

6.1.1 Projecting RCI values

In order to understand how the RCI might change over time it was necessary to establish deterioration trends for the individual RCI parameters. Whole carriageway and wheel track cracking were not trended because of the lower reliability in the measurements and due to the fact that the deterioration of cracking will not follow a curve, and will most likely have step changes once the road starts to crack. Figure 55 shows the established quadratic deterioration trends for the Texture, Rutting and LPV RCI parameters. The trends expected were established using engineering knowledge and previous experience with deterioration trending on the Highways Agency network. It is assumed that each 10m length will deteriorate at this defined rate, although it is understood and acknowledged that this will not be the case in practice.

The parameter trends were applied to the full SCANNER parameter dataset to “age” the data by one year and new RCI values were calculated using the trended data. A model was then established that described how the RCI values changed as a result of this deterioration. This model was based on defining, for each possible RCI value, the probability that the RCI would be unchanged or would increase by one, or by two, etc. established for this project.

Table 31 shows a sample of the resulting projection model that is displayed in Figure 56. This shows that, in one year:

- A sizeable proportion of RCI values do not change
- A sizeable proportion of RCI values increase by 5 and 10 units
- A smaller proportion of RCI values change by other amounts

In the trajectory model, these probabilities are applied to the initial year RCI frequency distribution. This is achieved by an iterative process: for example, for all RCI values of 0 in the initial year, 77.22% are unchanged in year 1, 1.80% are increased by 1 in year 1, 1.73% are increased by 2, etc. The same approach is applied to RCI values of 1 in the initial year, continuing up to initial RCI values of 370 (the maximum RCI value). This approach projects the current year RCI frequency distribution to a year 1deteriorated distribution.

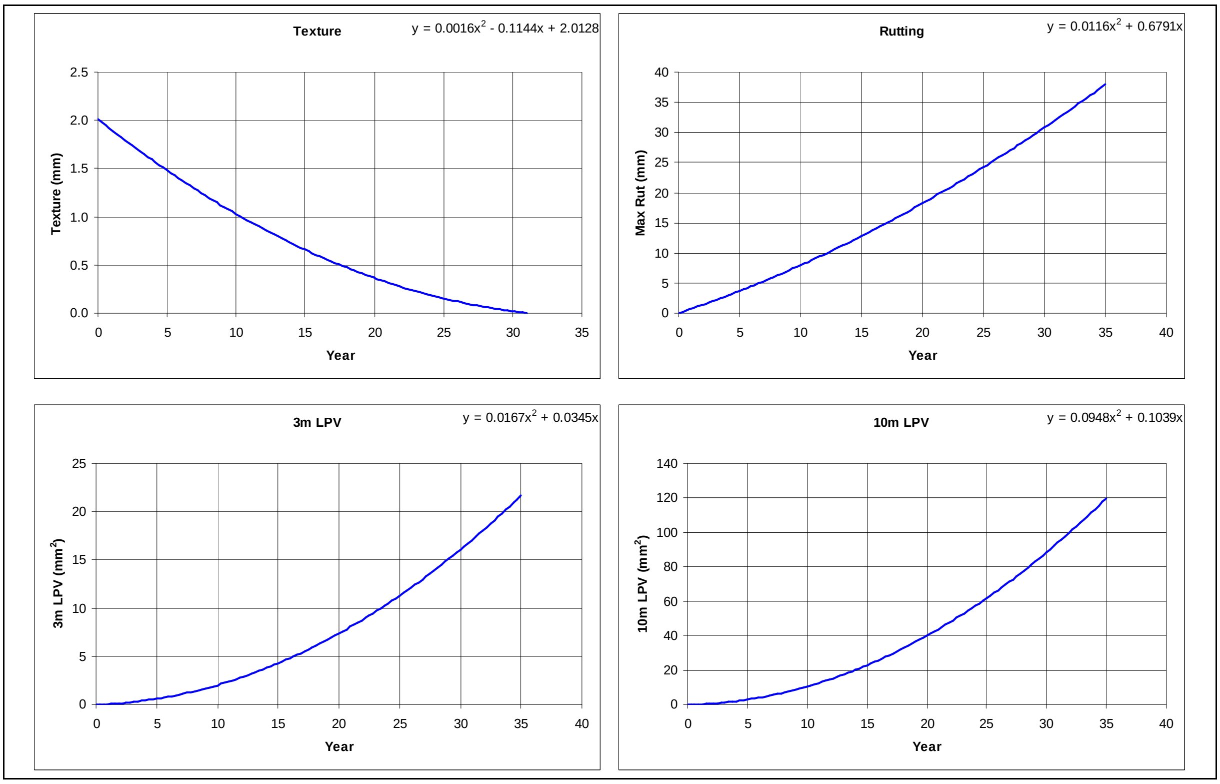


Figure 55: Parameter deterioration trends

Lower RCI Band	Upper RCI Band	Probability of observing specified change in RCI value				
		0	1	2	3	…
0	9	77.22%	1.80%	1.73%	1.18%	…
10	19	23.00%	0.67%	0.57%	1.25%	…
20	29	18.98%	0.56%	0.47%	0.81%	…
30	39	18.20%	0.56%	0.49%	0.71%	…
40	49	18.97%	0.58%	2.51%	3.08%	…
50	59	40.78%	1.53%	1.61%	1.87%	…
60	79	27.38%	1.23%	1.07%	1.59%	…
80	99	30.40%	1.37%	1.48%	1.87%	…
100	119	4.92%	0.36%	0.38%	1.17%	…
120	139	4.18%	0.84%	1.08%	1.41%	…
140	159	36.87%	1.37%	1.45%	1.01%	…
160	179	10.71%	0.69%	0.57%	0.67%	…
180	199	19.60%	0.73%	1.17%	1.05%	…
200	219	19.59%	0.73%	0.65%	0.85%	…
220	370	27.53%	1.27%	1.27%	1.03%	…

Table 31: Sample data from RCI projection model

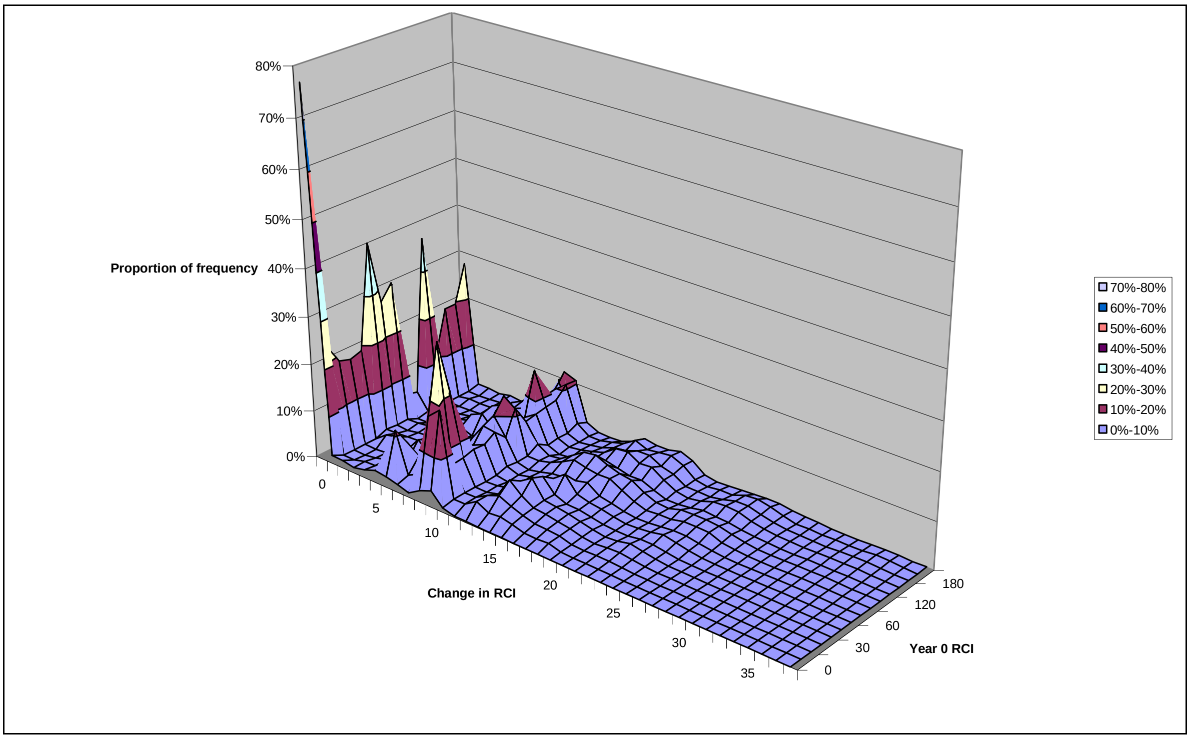


Figure 56: 3D plot of RCI projection model

Early trials of this projection showed that it predicted unrealistically rapid deterioration of the pavement probably due to the way in which the RCI model assumes that all the parameters deteriorate at the rate shown when, in practice, only some of the aspects of the pavement condition will change. Therefore, two slower models were developed, one at half the deterioration rate, and one at a third of this rate. By artificially underestimating the rate it is thought possible to counter the overestimate that resulted from having all the parameters added together to a single trend.

6.1.2 Application of maintenance lengths

The next stage of the trajectory model is to apply maintenance treatments to specified lengths, with associated efficiencies. This adjusts the RCI distribution to reflect the improvement in condition expected given the length that has been maintained. There are four types of maintenance for which the user can specify a maintenance length and associated efficiency:

- Local Patch – Typically replacing small lengths with high RCI values. Would not be expected to restore perfect condition.
- Resurfacing – Typically replacing longer lengths, which will contain a distribution of RCI values. Expected to result in good condition.
- Surface Dressing – Typically replacing lengths that have a lower proportion of high RCI values. Expected to result in a condition that is not as good as resurfacing.
- Reconstruction – Typically replacing high RCI values and resulting in good condition.

For each of these types of maintenance, the efficiency is represented by values input by the user:

  - o The percentage of the specified length which is typically in each RCI classification band before treatment (i.e. Red, Amber and Green), plus:

- The range of RCI values expected following treatment, specified as lower and upper RCI values.

The efficiency describes the extent to which the treatment type is expected to improve the condition of the network.

The application of a maintenance length is an iterative, two stage process. Firstly, for each 10m length maintained, a value is removed from the RCI distribution from within the appropriate classification band (e.g. 100 to 370 for Red). Secondly, a value for this 10m length is added within the range of RCI values expected after this type of treatment. Figure 57 shows the iterative process of maintaining 10m lengths in this way. The procedure starts at the upper end of the RCI band when subtracting (indicated by red blocks) and at the lower end of the RCI range when adding (indicated by green blocks). In this example, the maintenance efficiency is 100% red and the condition after maintenance is an RCI range of 0 to 2). For successive 10m lengths that are maintained, the position at which the length is removed from or added to the distribution is incremented, to avoid creating unrepresentative holes or spikes in the distribution. Once the end of the RCI band is reached, the process then loops back round through the RCI band again, continuing until the required amount of maintenance has been simulated.

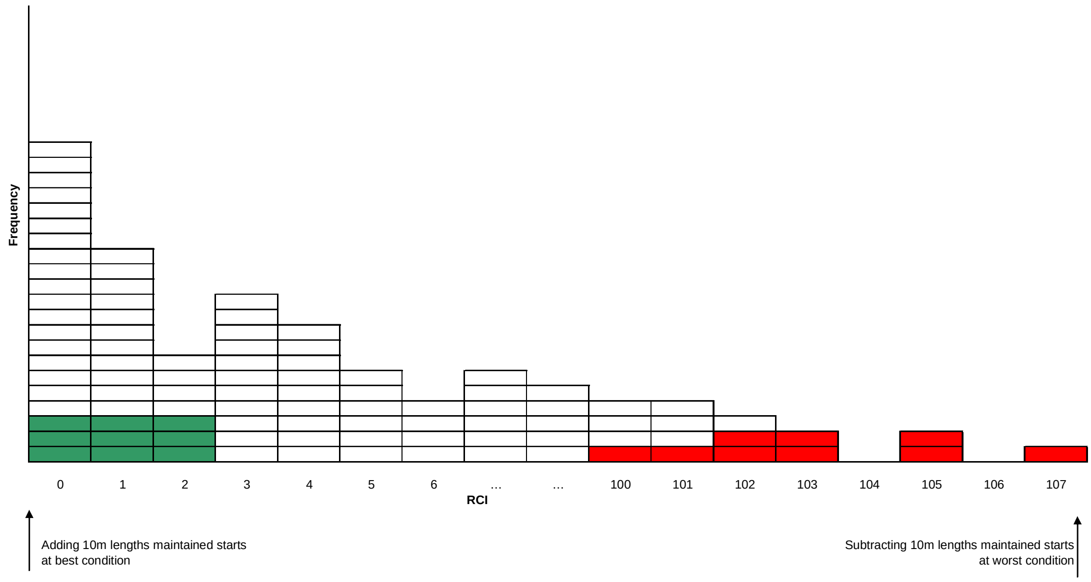


Figure 57: Illustration of application of maintenance within the trajectory model

6.1.3 Excel trajectory tool

An MS Excel spreadsheet was developed to implement the trajectory model. Figure 58 shows the user interface of the tool, which sets out the input requirements of the model in the main window. This is accompanied by additional windows that provide some basic statistics on the RCI distribution along with a plot for each of the 5 years. The data contained in Figure 58 is for a randomly chosen Authority, for which sample model results are given in Section 6.2.

The trajectory tool employs the following process for establishing the trajectory for a given RCI year:

1. Project condition of the RCI frequency distribution using the selected rate of condition deterioration (low, medium, high).

2. For each classification of RCI[1] (starting at Red, then moving to Amber and finally Green):
    a. Apply local patch - Calculate number of 10m lengths to maintain (multiply efficiency value for the relevant RCI band by maintenance length). Subtract length from the appropriate RCI classification band and add to the defined reset band for the treatment.
    b. Apply resurfacing - Calculate number of 10m lengths to maintain (multiply efficiency value for the relevant RCI band by maintenance length). Subtract length from the appropriate RCI classification band and add to the defined reset band for the treatment.
    c. Apply surface dressing - Calculate number of 10m lengths to maintain (multiply efficiency value for the relevant RCI band by maintenance length). Subtract length from the appropriate RCI classification band and add to the defined reset band for the treatment.
    d. Apply reconstruction - Calculate number of 10m lengths to maintain (multiply efficiency value for the relevant RCI band by maintenance length). Subtract length from the appropriate RCI classification band and add to the defined reset band for the treatment.
3. Copy maintained distribution to next year ready for applying deterioration projection (1) and maintenance (2).

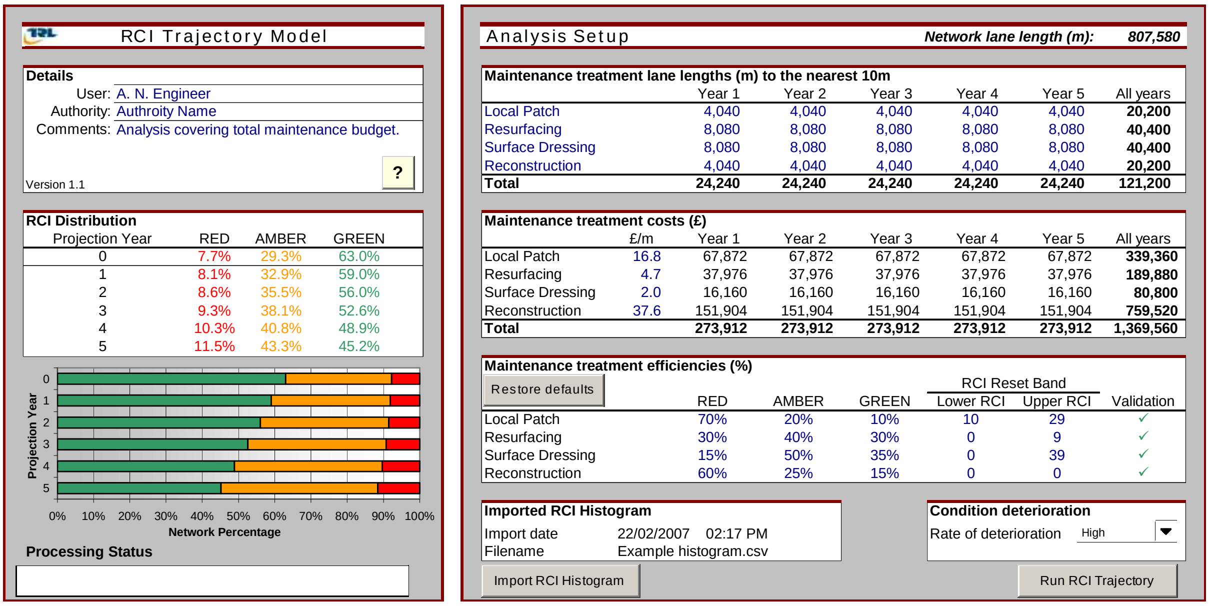


Figure 58: Trajectory model user interface

The trajectory tool also provides a more detailed analysis of how the model projects the full RCI distribution over the five years, which is shown in Figure 59. The figure shows the distribution for each year after the projection and application of maintenance. The user can also view just the projected distribution, although this is not shown here. The histograms show the changes in frequency of different bands of RCI score. According to the level of deterioration and the amount and type of maintenance used, these bands will respond differently, showing how the condition of the network is changing.

[1] If the maintenance length exceeds the length within the classification band (i.e. Red or Amber), the remainder of the maintenance length will be applied to the next classification band down (i.e. maintaining all of Red will mean the remainder length will be applied to Amber).

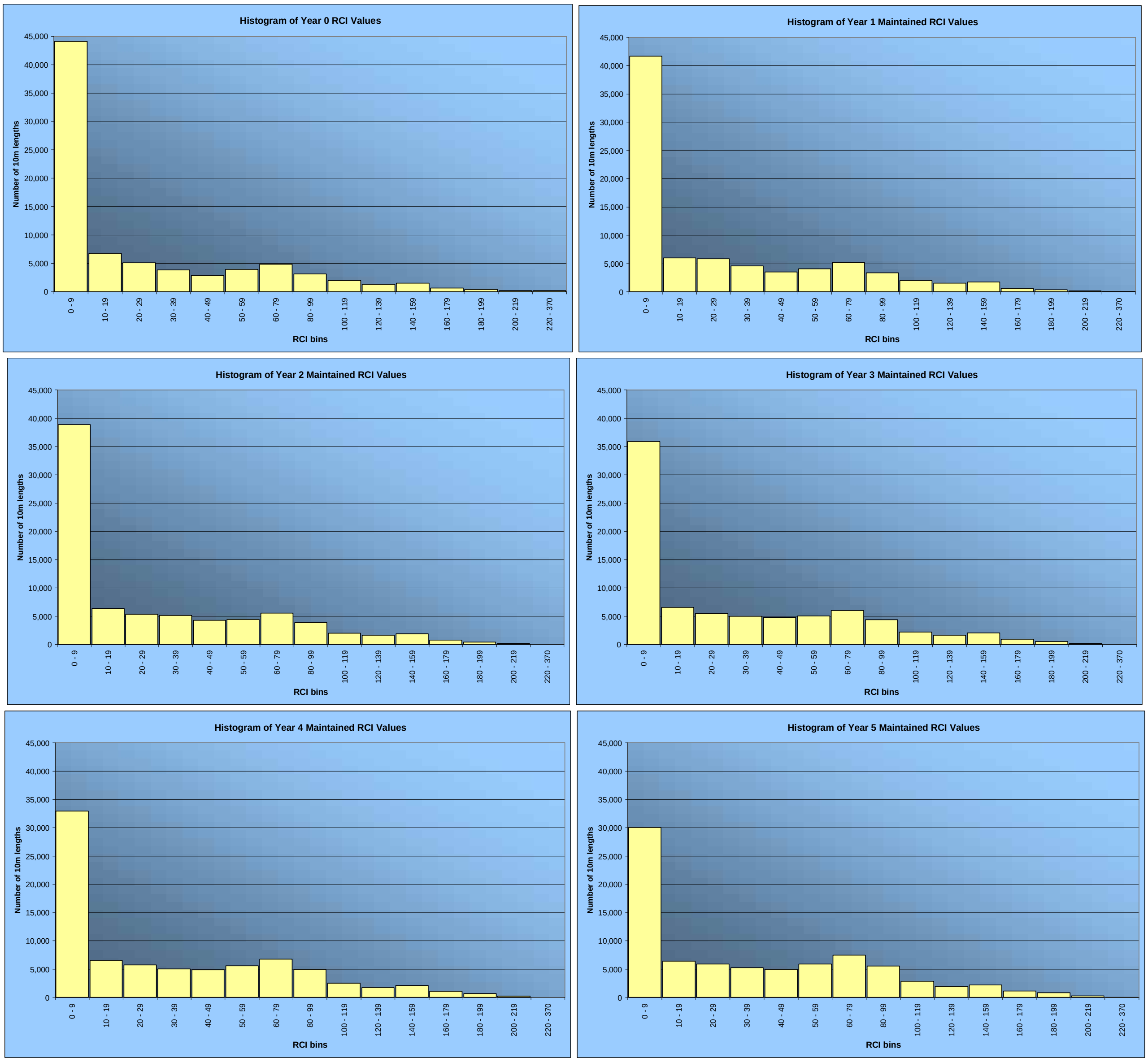


Figure 59: Change in RCI distribution each year using the Excel trajectory tool

6.2 Example RCI trajectories

The results presented in this Section have been produced using the RCI distribution for a typical authority. Although this example has been developed using real data, the results of the projection will require the judgement and interpretation of an engineer and should not be considered as proposed target RCI values. The model is not designed to produce a definitive answer regarding what **will** happen to the condition of a given network – merely to give some indication of what **may** happen given certain assumptions about the average rate of deterioration of a piece of road, and the effect of maintenance on that piece of road.

6.2.1 The effect of no maintenance

Figure 60 shows the Authority's RCI trajectory given the application of no maintenance, using each of the three available condition trend rates. This shows the effect of the projection element of the model. As expected the projection causes a rise in Red and Amber classifications and an equivalent fall in Green RCI lengths; this process is faster for the higher deterioration rates.

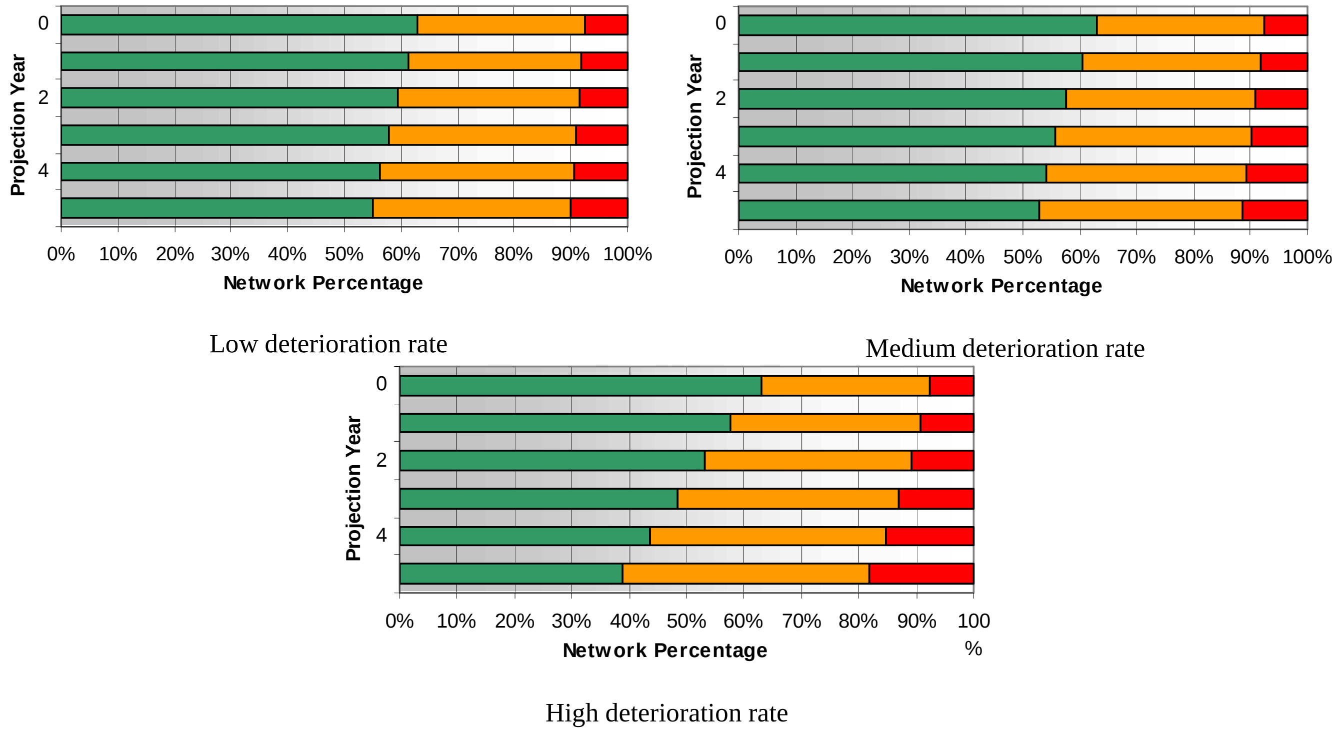


Figure 60: RCI trajectories given no maintenance

6.2.2 The effect of maintenance

As part of the liaison with local authorities, a number were able to provide information about the efficiencies of the four defined treatment types. Using this data along with engineering experience the efficiency figures shown in Table 32 were established. The RCI reset bands have been developed based on assumptions made regarding the effectiveness of each treatment in lowering the RCI. Users can edit these values through the main window of the trajectory tool.

Treatment type	**Condition before maintenance (% of length in each band)**			**Condition after maintenance (typical range of RCI values)**	
	RED	**AMBER**	**GREEN**	**Lower RCI**	**Upper RCI**
Local Patch	70%	20%	10%	10	29
Resurfacing	30%	40%	30%	0	9
Surface Dressing	15%	50%	35%	0	39
Reconstruction	60%	25%	15%	0	0

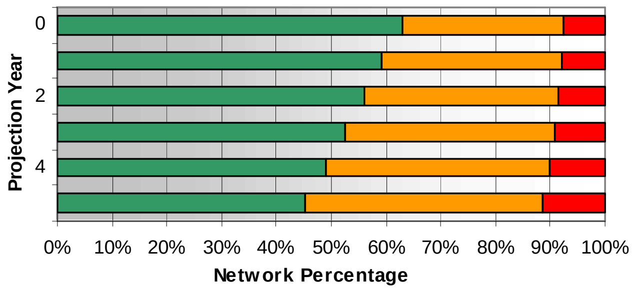
Table 32: Treatment efficiencies

Table 33 shows the maintenance lengths that were applied based on an assumed 3% network maintenance per year, split between the different types of maintenance according to cost, for each of the five years.

Treatment type	Maintenance length (m)					
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Total**
Local Patch	4040	4040	4040	4040	4040	20200
Resurfacing	8080	8080	8080	8080	8080	40400
Surface Dressing	8080	8080	8080	8080	8080	40400
Reconstruction	4040	4040	4040	4040	4040	20200

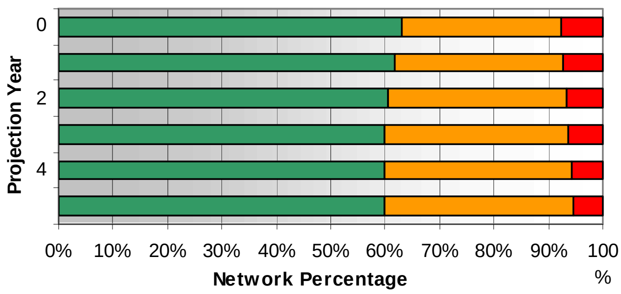
Table 33: Applied maintenance lengths

High deterioration rate



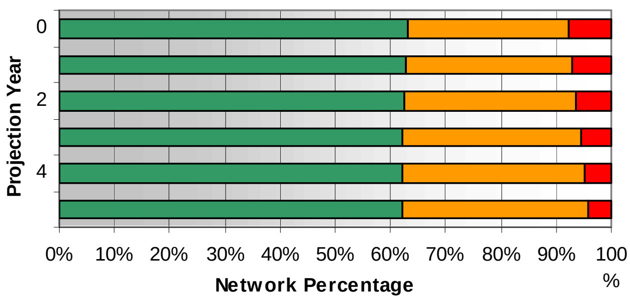
RCI Distribution Projection Year	RED	AMBER	GREEN
0	7.7%	29.3%	63.0%
1	8.1%	32.9%	59.0%
2	8.6%	35.5%	56.0%
3	9.3%	38.1%	52.6%
4	10.3%	40.8%	48.9%
5	11.5%	43.3%	45.2%

Medium deterioration rate



RCI Distribution Projection Year	RED	AMBER	GREEN
0	7.7%	29.3%	63.0%
1	7.2%	31.0%	61.8%
2	6.8%	32.6%	60.6%
3	6.4%	33.6%	60.0%
4	5.9%	34.2%	59.9%
5	5.4%	34.6%	60.0%

Low deterioration rate



RCI Distribution Projection Year	RED	AMBER	GREEN
0	7.7%	29.3%	63.0%
1	7.0%	30.3%	62.8%
2	6.3%	31.3%	62.5%
3	5.6%	32.3%	62.1%
4	4.9%	33.1%	62.0%
5	4.1%	33.6%	62.3%

Figure 61: Results predicted using RCI trajectory with 3% applied maintenance

The plots in Figure 61 show the sensitivity of the model to the three levels of deterioration that are available in the model. For this authority the Medium level seems to agree best with an independent suggestion: that under 3% maintenance the condition of the network might be expected to stay close to steady state. Conversely, with the High deterioration, the overall condition worsens under 3% maintenance, and with the Low deterioration the condition appears to improve. In use, authorities may wish to view projections at each rate which is possible by simply selecting a level from the drop down menu.

6.3 Summary

A trajectory tool has been developed that allows a local authority to explore the possible consequences of a range of maintenance scenarios on the condition of the network. This is based on the initial condition of the network and simple assumptions about the effects of deterioration and maintenance. It should be noted that, while basic tests indicate the behaviour is reasonable, the model has not been subject to extensive testing to validate the parameter values used.

Further improvement to the accuracy of the model would require a much greater level of complexity and detract from the simplicity of the input and output. However, it is recommended that, as more information becomes available about changes in RCI values over time and with maintenance, further work is undertaken to develop the projection and maintenance algorithms.

The user guide supplied with the tool, and included in Appendix E, gives more information on the use of the tool and runs through an example.

7 Further Development of the RCI

The SCANNER research programme has delivered a number of new parameters for assessing the condition of road surfaces. The reporting of these parameters became a requirement of SCANNER in 2006, although it is not expected that all contractors will be able to successfully deliver them until 2007. These parameters are

- Edge step level 1
- Edge step level 2
- Edge roughness
- Transverse variance
- Transverse unevenness (ADFD)
- Cleaned rutting (Nearside and Offside)

The current RCI does not provide the facility to incorporate these parameters when assessing the condition of the network. Work has therefore been carried out to review the behaviour of these parameters and propose how they may be included in an “extended” RCI.

7.1 The new SCANNER parameters

The first four of the above parameters provide information on the condition of the edge of the road. Although they are calculated separately, the research programme has suggested a method of combining these into a single Edge Condition Indicator (ECI):

$$ECI = [25 \times E_{S1}] + [30 \times E_{S2}] + [30 \times E_R] + [15 \times E_{TV}]$$

where E_{S1}, E_{S2}, E_R and E_{TV} represent the score obtained the 10m length using the measured value of each parameter (i.e. E_{S1} is the score obtained using the measured value of Edge Step Level 1). The score for each parameter is determined using the same approach used in the current RCI, i.e. it is defined by a linear progression from 0 to 100 applied between two defined thresholds.

The approach of combining scores to obtain an overall edge condition score (ECI) for the 10m length was proposed within the research because it was felt that, individually, the edge deterioration parameters could be subject to considerable error. However, by scoring, weighting and combining them, we would obtain a single indicator that would identify lengths containing edge deterioration with a reasonable degree of confidence. The research proposed thresholds for the calculations of the scores within the RCI, but these were based on a reasonably small dataset. The larger dataset available within this work should enable us to further refine these thresholds.

The Transverse unevenness parameter (also known as the Absolute Deviation of the First Derivative, ADFD) is a measure of the unevenness of the road across the full survey width. This parameter can be compared with rutting, in that is often reports high values where there is rutting present. However the parameter also indicates the presence of non-rutting transverse profile “features”.

The cleaned rutting parameter provides an indication of the level of rutting present on a length of pavement. This parameter is closely aligned with the traditional measurement of rutting already included in the current RCI. However, the rutting is calculated after discarding points measured off the carriageway that could adversely affect the accuracy of the traditional measurement of rutting. The measure is therefore more accurate, and less susceptible to errors caused by features such as road markings. Because of the high level of agreement between this parameter and the traditional measurement of rutting (demonstrated in the research). It is considered that this parameter will simply replace the existing rut parameter in the RCI (as a direct swap), once its robustness has been confirmed in the network survey. This inclusion would incorporate the same thresholds and weightings as used for the current RCI. Therefore this work has not investigated the use of this parameter.

Recent research carried out into the measurement of shape has proposed further parameters for the assessment of road condition – Enhanced LPV and the bump measure. Enhanced LPV is a measure of ride quality calculated from the longitudinal profile data using more advanced filtering techniques than the current moving average approach. This makes the measure less susceptible to the effects of road geometry than the Moving Average method. The bump measure also uses longitudinal profile to identify bumps present on the network. However, because these measures will only become a requirement of SCANNER in 2007 no data was available to investigate the use of them within an extended RCI.

Work has also been carried out in the SCANNER research into the measurement of texture. This has proposed a texture Variability parameter to identify distress. Again, this measure will only become a requirement of SCANNER in 2007 and hence no data was available to investigate the use of it within an extended RCI.

7.2 Data source for assessment of the new SCANNER parameters

As discussed in Section 2, only WDM were able to supply data on the new parameters. The data provided by WDM for this assessment is summarised by LA in Table 34 and by road classification in Table 35. Unfortunately, because only WDM could supply the new parameter data, and because Bracknell Forest was surveyed by Jacobs-Babtie, it was not possible to investigate the impact of the new parameters on the Workshop sites.

Authority	**Length (km)**
Bexley	86
Cambridgeshire	937
Harrow	51
Leicestershire⌘	729
Lincolnshire	2093
Perth and Kinross	465
South Lanarkshire*	644
Surrey	896
Torbay	90
Total	**5991**

More Leicestershire data was processed successfully in the new parameter phase of the research than previously.
*South Lanarkshire data became available at a late stage in the research, so was used in the new parameter investigation only.

Table 34: New parameter data used in research.

Road Class	**A**	**B**	**Minor Rural**	**Minor Urban**
Length (km)	2405	1879	1112	595

Table 35: Lengths of A, B, Minor Rural and Minor Urban roads in new parameter dataset.

7.3 Examination of edge parameters

7.3.1 Edge Step Level 1

Edge Step Level 1 is a measure of the proportions of each subsection (typically 10m) that exhibits a step down at the nearside edge of the road that has a step height between 20mm and 50mm. The value is expressed as a percentage, so a 10m subsection which has no such step at the edge will report 0%, a 10m subsection with 1m affected will score 10%, and a 10m subsection where the whole 10m shows such a step will report 100%. Table 36 shows how much of the dataset contained zero for Edge Step Level 1 (i.e. exhibited no steps). Figure 62 shows the distribution of values of Edge Step Level 1 on A, B, Minor Rural and Minor Urban roads.

As can be seen in Table 36 and Figure 62, most of the network is not affected by steps having heights that trigger the recording of Edge Step Level 1. This is especially true on A roads, where over 93% of all surveyed lengths showed no such step down. The rest of the dataset (B, C and U roads) appears to contain broadly similar percentages of Edge Step Level 1. Table 37 shows the 80th, 90th, 95th, 96th, 97th 98th 99th and 100th percentile values for Edge step level one on for A, B, minor rural and minor urban roads.

A	B	Minor Rural	Minor Urban
93.10	80.70	78.31	80.87

Table 36: Proportions of A, B, Minor Rural and Minor Urban roads with zero Edge Step Level 1.

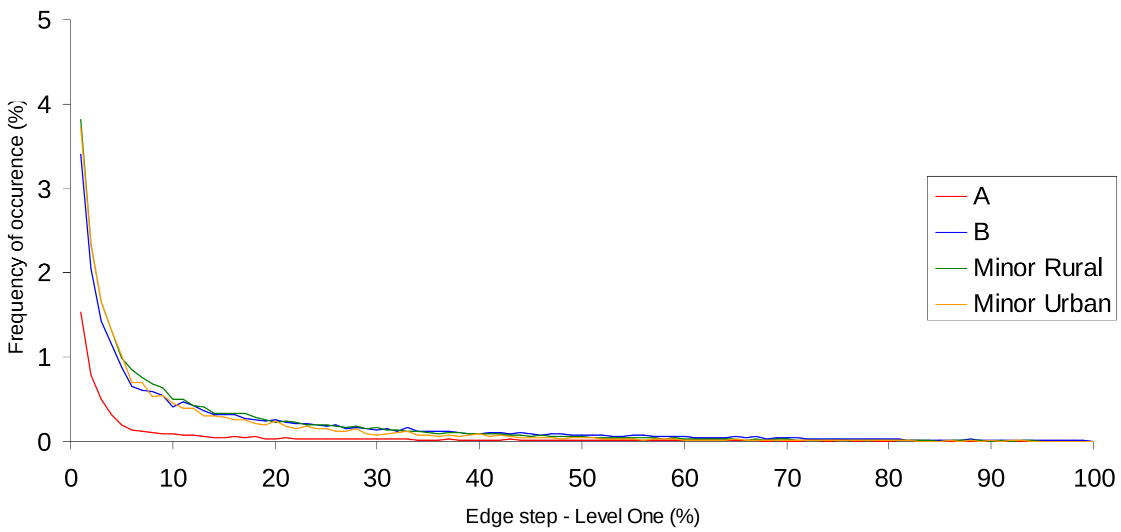


Figure 62: Frequency of occurrence of amounts of Edge Step Level one on A, B, Minor Rural and Minor Urban roads.

Edge steps can be considered to be a safety defect, and as such they are equally as important on all roads. Experience has shown that very little of the A road network is affected by edge deterioration. Urban roads are also unlikely to be affected, as these tend to have supported edges. It is felt that, when selecting threshold values for determining the score for Edge Step Level 1 within the Edge Condition Indicator (ECI), they should reflect this expected behaviour, and hence not result in an unrealistic proportion of urban, or A roads, being flagged as suffering from edge deterioration. Table 38 shows proposed thresholds for use with Edge Step Level 1 data.

n^{th} Percentile	A	B	Minor Rural	Minor Urban
80	0	0.3	0.9	0.3
90	0	6.3	7.3	4.7
95	1.3	20.8	19.0	14.0
96	2.3	26.2	23.6	17.7
97	4.1	33.9	29.2	22.7
98	10.0	44.4	37.4	30.7
99	26.7	60.3	51.3	44.3
100	100	100	100	100

Table 37: Values for Edge Step Level 1 at various percentile levels on A, B, Minor Urban and Minor Rural roads.

	A		**B**		**Minor Rural**		**Minor Urban**	
Parameter	T_L	T_U	T_L	T_U	T_L	T_U	T_L	T_U
Edge Step Level 1	7	20	7	20	7	20	7	20

Table 38: Proposed thresholds for use with Edge Step Level 1 data.

7.3.2 Edge Step Level 2

Edge Step Level 2 is a measure of the proportion of each subsection (typically 10m) exhibits a step down at the nearside edge of the road greater than 50mm. The value is expressed as a percentage, so a 10m subsection which has no such step at the edge will report 0%, a 10m subsection with 1m affected will score 10%, and a 10m subsection where the whole 10m shows such a step will report 100%. Table 39 shows how much of the A, B, Minor Rural and Minor Urban roads in the new parameter dataset contained zero for Edge Step Level 1 (i.e. exhibited no such steps). Figure 63 shows the distribution of different levels of Edge Step Level 2 on A, B, Minor Rural and Minor Urban roads. It can be seen in Figure 63 and Table 40 that such steps occur very infrequently, on any class of road, but that A roads are typically affected by steps of this magnitude less frequently than the other classes of road. Almost 99% of all A roads in the TRL new parameter dataset exhibit no steps down at Step Level 2. As with Edge Step Level 1, the rest of the roads (B, C and U) seem to show similar distributions of steps, at this larger Step Level.

A	B	Minor Rural	Minor Urban
98.64	94.79	93.21	95.08

Table 39: Proportions of A, B, Minor Rural and Minor Urban roads with zero Edge Step Level 2.

As with Edge Step Level 1, it is unlikely that much of the A road network will be affected by severe (50mm+) stepping. Urban roads are also unlikely to be affected as these typically have supported edges. The threshold values chosen for use within the Edge Condition Indicator (ECI) should reflect this and should not result in an unrealistic proportion of urban, or A roads, being flagged as suffering from edge deterioration. On the other hand, the severity of the stepping means it is potentially very serious and should be flagged when present. For this reason the initial research in to the development of the edge parameters (Watson et al, 2005) suggested that any length containing a step at Level 2 should score highly. Because the presence of only 1 transverse profile in any 10m subsection would result in the reporting of a step down the upper threshold was therefore “any non zero value”. However, assessment of the network data in this work shows that this would produce an indicator which was too aggressive, reporting edge deterioration too often. Slightly higher thresholds are therefore proposed (as shown in Table 41) which reflect the severity of the parameter, but do not result in an unrealistic proportion of urban, or A roads, being flagged as suffering from edge deterioration.

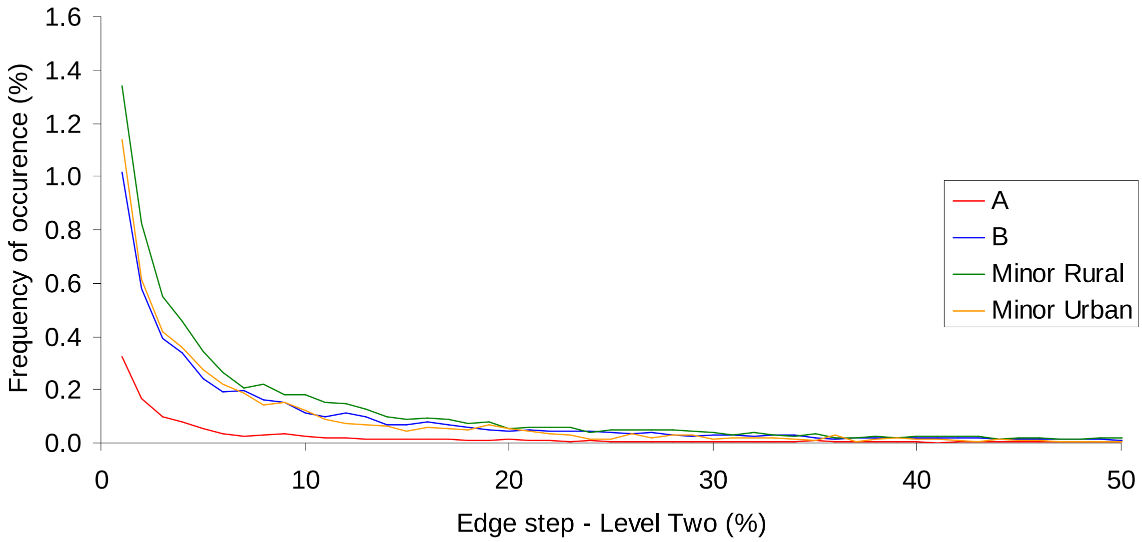


Figure 63: Frequency of occurrence of amounts of Edge Step Level 2 on A, B, Minor Rural and Minor Urban roads.

n^{th} Percentile	A	B	Minor Rural	Minor Urban
80	0	0	0	0
90	0	0	0	0
95	0	0.7	2.0	0.4
96	0	1.8	3.7	1.3
97	0	4.0	6.7	3.0
98	0	9.0	12.0	6.1
99	1.6	21.8	25.9	15.2
100	100	100	100	100

Table 40: Various percentile level values for Edge Step Level 2 on A, B, Minor Urban and Minor Rural roads.

	A		B		Minor Rural		Minor Urban	
Parameter	T_L	T_U	T_L	T_U	T_L	T_U	T_L	T_U
Edge Step Level 2	0	5	0	5	0	5	0	5

Table 41: Proposed thresholds for use with Edge Step Level 2.

7.3.3 Edge Roughness

Edge Roughness is a measure of how much short wavelength roughness is present at the nearside edge of the carriageway. Figure 64 shows the distribution of Edge Roughness values on the different road classes. Table 42 shows the 80th, 90th, 95th, 96th, 97th 98th 99th and 100th percentile values for Edge Roughness on for A, B, Minor Rural and Minor Urban roads. It can be seen in Figure 64 and Table 42 that A roads are affected by Edge Roughness less frequently than the other classes of road. As before, the threshold values chosen for use within the Edge Condition Indicator (ECI) should reflect the likely occurrence and seriousness of edge deterioration occurring on the various road classes, and should not result in an unrealistic proportion of urban, or A roads, being flagged as suffering from edge deterioration. Table 43 shows the proposed threshold values.

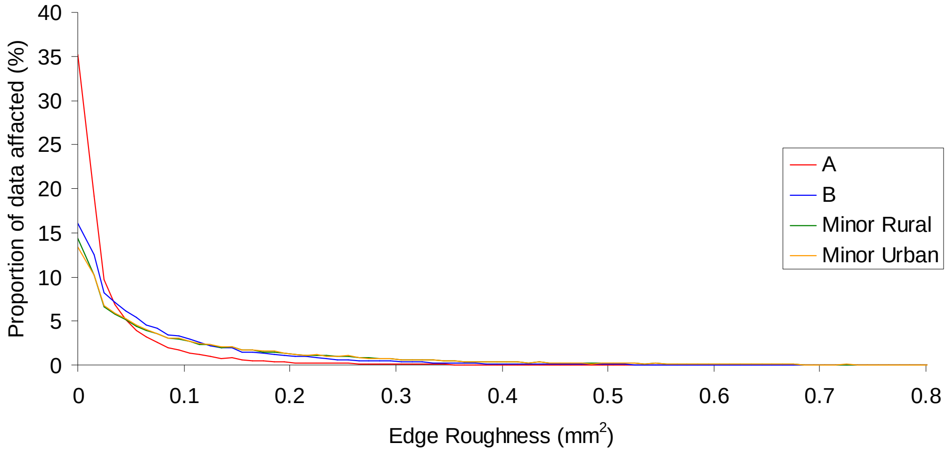


Figure 64: Frequency of occurrence of amounts of Edge Roughness on A, B, Minor Rural and Minor Urban roads.

nth Percentile	A	B	Minor Rural	Minor Urban
80	0.06	0.13	0.21	0.18
90	0.11	0.21	0.32	0.28
95	0.17	0.28	0.44	0.38
96	0.19	0.30	0.47	0.41
97	0.22	0.34	0.51	0.45
98	0.26	0.38	0.56	0.50
99	0.34	0.45	0.65	0.57
100	0.81	0.88	0.90	0.86

Table 42: Various percentile level values for Edge Roughness on A, B, Minor Urban and Minor Rural roads.

	A		**B**		**Minor Rural**		**Minor Urban**	
Parameter	T_L	T_U	T_L	T_U	T_L	T_U	T_L	T_U
Edge Roughness	0.2	0.3	0.2	0.3	0.3	0.5	0.3	0.5

Table 43: Proposed thresholds for use with Edge Roughness data.

7.3.4 *Transverse Variance*

Transverse variance is a measure of how much more uneven the nearside half of the carriageway is than the offside half. This is calculated by calculating the short wavelength transverse profile variance for each half of the carriageway and then subtracting the right hand value from the left hand one. If the resulting value is large and positive then the nearside is considerably more uneven than the offside. This nearside unevenness is then taken to indicate the presence of edge deterioration. Figure 65 shows the distribution of Transverse Variance values on the different road classes. This shows that less Transverse Variance is recorded on A roads than the rest of the dataset, and that slightly more is recorded on Urban C and U roads, with B roads and Rural c or U roads showing very similar distributions.

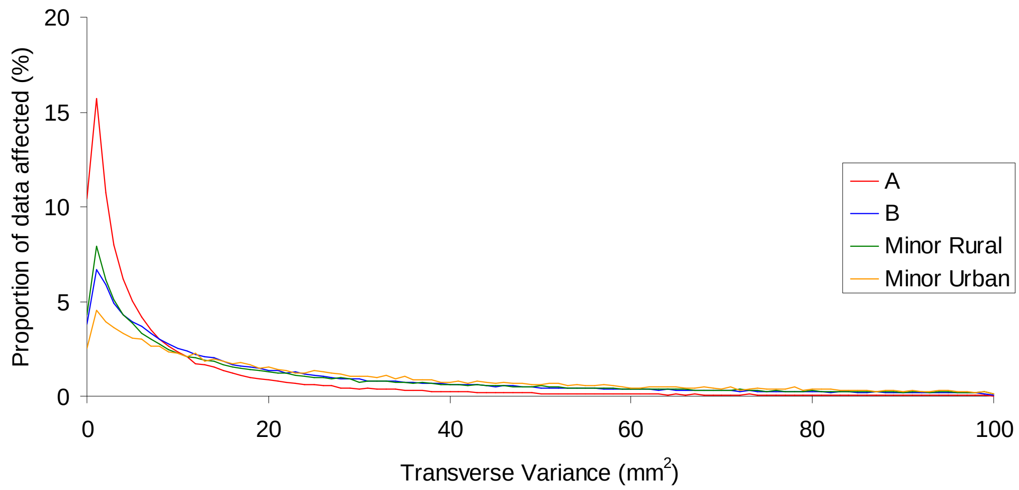


Figure 65: Frequency of occurrence of amounts of Transverse Variance on A, B, minor Rural and Minor Urban roads.

Table 37 shows the 80th, 90th, 95th, 96th, 97th 98th 99th and 100th percentile values for Transverse Variance on for A, B, Minor Rural and Minor Urban. As with all the other measures of edge deterioration, Figure 65 and Table 37 show that A roads are affected by higher values of this parameter much more infrequently than the other classes of road. As before, the threshold values chosen for use within the Edge Condition Indicator (ECI) should reflect the likely occurrence and seriousness of edge deterioration occurring on the various road classes, and should not result in an unrealistic proportion of Urban, or A roads, being flagged as suffering from edge deterioration. Table 45 shows the proposed threshold values.

nth Percentile	**A**	**B**	**Minor Rural**	**Minor Urban**
80	9.97	40.80	50.66	61.09
90	25.44	92.02	127.21	127.06
95	59.01	176.04	251.25	232.80
96	77.20	212.59	303.78	278.41
97	108.50	267.18	377.23	343.28
98	174.76	353.73	485.84	445.16
99	328.44	528.14	701.39	647.37
100	2026.35	2090.26	1756.97	2261.54

Table 44: Various percentile level values for Transverse Variance on A, B, Minor Urban and Minor Rural roads.

	A		B		Minor Rural		Minor Urban	
Parameter	T_L	T_U	T_L	T_U	T_L	T_U	T_L	T_U
Transverse Variance	100	250	100	250	100	250	100	250

Table 45: Proposed thresholds for use with Transverse Variance.

7.4 Examination of the transverse unevenness parameter – ADFD

The transverse unevenness (Absolute Deviation of the First Derivative of the transverse profile (ADFD)) is a measure of how uneven the carriageway is, in a direction perpendicular to the direction of travel. The parameter is essentially a measure of how much deviation from a straight line there is in the transverse profile of the carriageway. The parameter has been seen to correlate well with rut depth measurements (Nesnas, et al., 2004), but also responds to non-rutting transverse profile features. Figure 66 shows the distribution of ADFD values on the A, B, Minor Rural and Minor Urban roads in the new parameter dataset. Table 46 shows the 80th, 90th, 95th, 96th, 97th 98th 99th and 100th percentile values for ADFD for A, B, Minor Rural and Minor Urban roads.

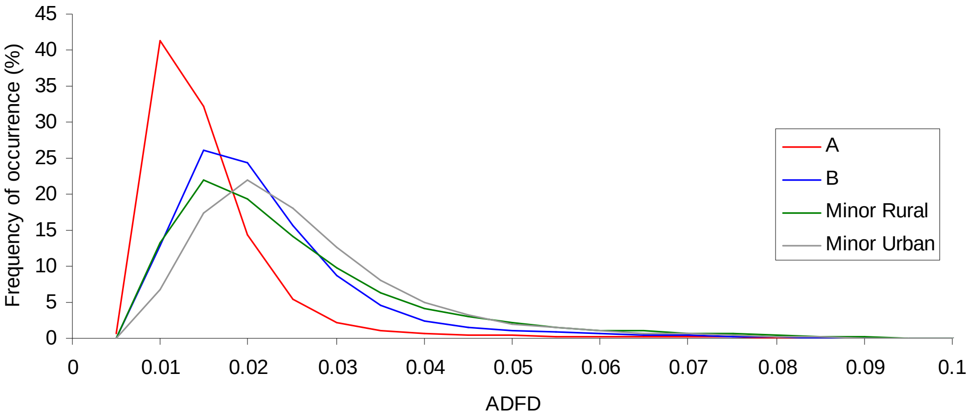


Figure 66: Frequency of occurrence of amounts of ADFD on A, B, Minor Rural and Minor Urban roads.

nth Percentile	A	B	Minor Rural	Minor Urban
80	0.016	0.025	0.031	0.031
90	0.020	0.031	0.041	0.040
95	0.026	0.040	0.052	0.049
96	0.029	0.043	0.056	0.053
97	0.033	0.048	0.060	0.057
98	0.040	0.054	0.066	0.063
99	0.053	0.062	0.073	0.072
100	0.108	0.125	0.121	0.834

Table 46: Various percentile level values for ADFD on A, B, Minor Rural and Minor Urban roads.

The ADFD parameter is likely to be used in conjunction with the rut depth measurement in the calculation of the RCI. However, because the parameter is so closely linked to rut depth, care must be taken to avoid a situation where rutting is effectively double counted. Table 47 shows the co-occurence of unweighted rutting and ADFD scores in the new parameter dataset. It can be seen that there are proportions of the dataset where each parameter can score highly, in the absence of the other. However, there is a higher proportion where the ADFD parameter scores highly in the absence of rutting (upper right of Table 47), than vice-versa (lower left of Table 47). This reflects the ability of the parameter to respond to both rutting and other types of transverse unevenness, but shows a need to take care with the use of the parameter, to avoid double counting, as discussed in section 7.6.

		ADFD						
		0	>0 and <20	>=20 and <40	>=40 and <60	>=60 and <80	>=80 and <100	100
Rutting	0	**87.78**	1.25	1.03	0.73	0.57	0.44	0.55
	>0 and <20	3.94	**0.07**	0.06	0.04	0.03	0.02	0.02
	>=20 and <40	1.68	0.04	**0.03**	0.02	0.01	0.01	0.01
	>=40 and <60	0.75	0.02	0.02	**0.01**	0.01	0.01	0.01
	>=60 and <80	0.35	0.01	0.01	0.01	**0.01**	0.00	0.00
	>=80 and <100	0.17	0.01	0.01	0.00	0.00	**0.00**	0.00
	100	0.18	0.01	0.01	0.01	0.00	0.00	**0.02**

Table 47: Co-occurrence of unweighted scores of ADFD and rutting.

Following consultations with engineers, it was recommended in Section 3.2.11 that the rut thresholds should be the same on all classes and environments of road. Therefore the threshold values chosen for ADFD data within the Edge Condition Indicator (ECI) should also be unified across the various road classes. Table 48 shows the proposed threshold values.

	A		**B**		**Minor Rural**		**Minor Urban**	
Parameter	T_L	T_U	T_L	T_U	T_L	T_U	T_L	T_U
ADFD	0.04	0.07	0.04	0.07	0.04	0.07	0.04	0.07

Table 48: Proposed thresholds for use with ADFD data.

7.5 Proposed thresholds for new parameters

Table 49 summarises the thresholds proposed in the preceding sections for the new parameters.

	A		**B**		**Minor Rural**		**Minor Urban**	
Parameter	T_L	T_U	T_L	T_U	T_L	T_U	T_L	T_U
Edge Step Level 1	**7**	**20**	**7**	**20**	**7**	**20**	**7**	**20**
Edge Step Level 2	**0**	**5**	**0**	**5**	**0**	**5**	**0**	**5**
Edge Roughness	**0.2**	**0.3**	**0.2**	**0.3**	**0.3**	**0.5**	**0.3**	**0.5**
Transverse Variance	**100**	**250**	**100**	**250**	**100**	**250**	**100**	**250**
ADFD	**0.04**	**0.07**	**0.04**	**0.07**	**0.04**	**0.07**	**0.04**	**0.07**

Table 49: Proposed values for T_L and T_U for use with new parameters.

7.6 Including the new parameters within the SCANNER RCI

The research has shown that the new parameters give potentially useful data about the condition of the road which were previously unavailable, and they should therefore be included within the RCI. This work has proposed thresholds (Section 7.5) based on the most up to date dataset. However, the work has not undertaken comparisons with "ground truth" data to fully assess the levels against engineer's opinion, and has been restricted to the measurements provided by a single survey contractor. The thresholds may therefore require revision following further data collection, and experience.

When considering the addition of the new parameters to the RCI we have assumed that these will be added following implementation of the revised settings, detailed in Section 3.2.16.

It is proposed that the ADFD parameter be added to the RCI as part of a family group, incorporating rutting (or cleaned rutting) and ADFD. However, the ADFD would be weighted at 0.7. When reporting the score from the family, only the maximum will be reported, and used to contribute to the total RCI. By combining them in a family the potential for double counting, which would arise from the known relationship between rut depth and ADFD, are avoided. It is proposed that the ADFD parameter be weighted at 0.7 to reflect the lower level of significance of non-rutting transverse features. By setting the weighting at 0.7 it is guaranteed that the weighted ADFD will never be greater than the weighted contribution from a rut depth of 17mm or greater.

Including ADFD in a family with rutting data produces a modified version of the Revised RCI, referred to as the Extended RCI. However, to complete the Extended RCI requires the addition of the edge parameters.

It is proposed that the edge parameters by addition of the ECI score to the RCI, but at a weighting of 0.5:

$$RCI_{ext} = RCI_{rev} + (0.5 \text{ x } ECI)$$

Because the ECI has a maximum score of 100 points this effectively gives edge deterioration a maximum contribution to the Extended RCI of 50 points, reducing its importance in the calculation of the Extended RCI to a level slightly less that carriageway cracking (60 points maximum), and equal to that of texture on Minor Rural roads (50 points maximum). The ECI will be more important in the RCI than texture on Minor Urban roads (30 points maximum). The maximum possible score from the extended RCI is then 365 on A or B roads, 340 on Minor Rural roads, and 320 on Minor Urban roads.

Note that there would be no need to alter the Amber and Red thresholds from their current values of 20 and 100, as the new parameters represent additional defects, not replacement ones.

7.7 Effect on RCI

7.7.1 Frequency of contribution

Using the threshold values proposed above (Table 49), the frequencies at which each parameter would contribute to the proposed ECI, and the ECI would contribute to the extended RCI were then investigated, and are shown in Figure 67 to Figure 70. These plots are similar to those shown in Figure 7 to Figure 10 for the existing SCANNER parameters.

These plots show how much of each of the new parameters (Edge Step level 1, Edge Step level 2, Edge Roughness, Transverse Variance and ADFD), contributed non-zero scores to the ECI or RCI. Also shown is how much of the network is affected by a non-zero ECI score, contributing to the RCI.

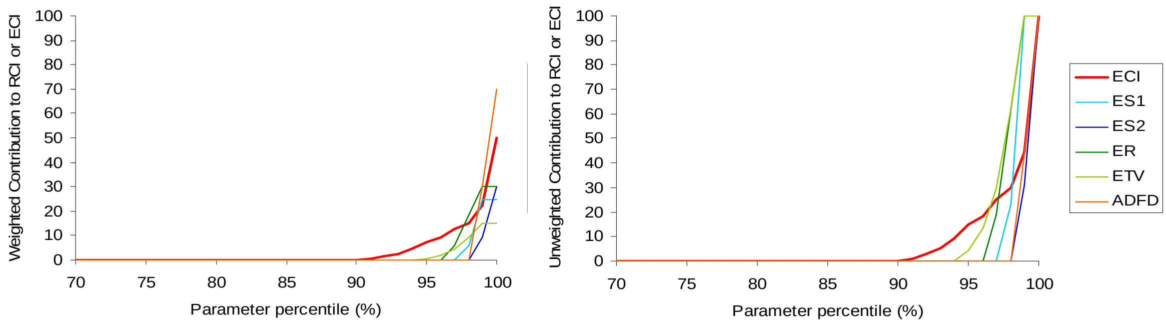


Figure 67: Contribution of each of the new parameters to the ECI, and of the ECI to the RCI for <u>A</u> roads. Left plot shows weighted contributions, right plot shows unweighted contributions.

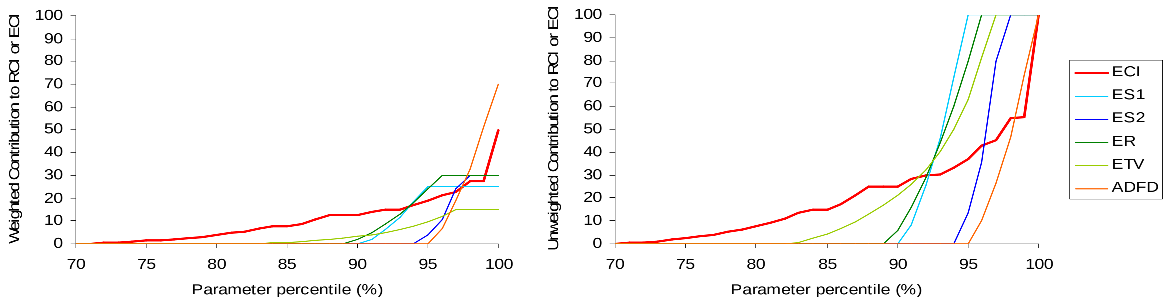


Figure 68: Contribution of each of the new parameters to ECI, and of the ECI to the RCI for <u>B</u> roads. Left plot shows weighted contributions, right plot shows unweighted contributions.

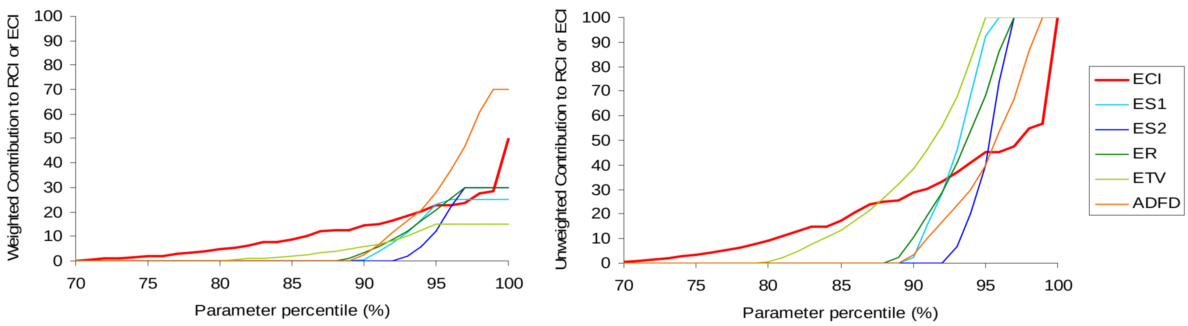


Figure 69: Contribution of each of the new parameters to ECI, and of the ECI to the RCI for <u>Minor Rural</u> roads. Left plot shows weighted contributions, right plot shows unweighted contributions.

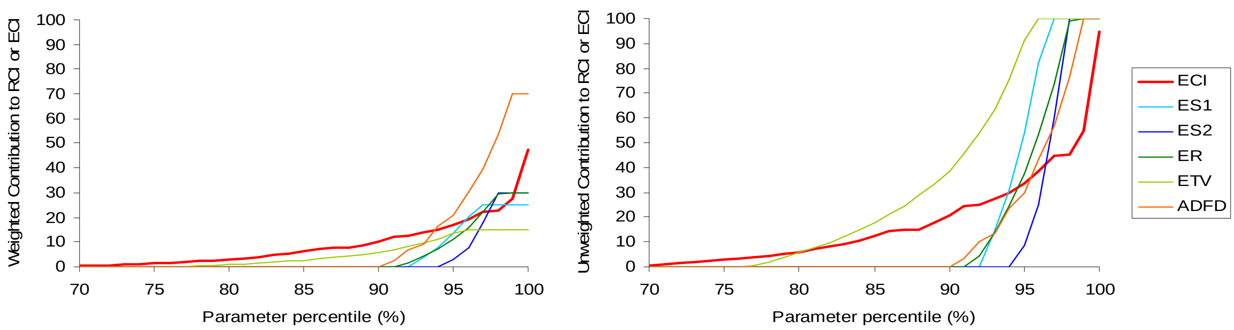


Figure 70: Contribution of each of the new parameters to ECI, and of the ECI to the RCI for <u>Minor Urban</u> roads. Left plot shows weighted contributions, right plot shows unweighted contributions.

7.7.2 *Behaviour of the Extended RCI*

Figure 71 shows the distribution of values obtained using the current RCI model, by class, when calculated using the dataset employed in the development of the Extended RCI (Table 34). This shows that A roads tend to have lower RCI values than the other classes, B roads have fewer high RCI values, and there is not much difference between the rural and urban minor roads. Figure 72 shows the distribution of (un-weighted) ECI scores by class obtained using the same dataset. The ECI has been calculated using the thresholds described in Section 7.5 and the method in Section 7.1. This shows that A roads show far less edge deterioration than the other classes, and that, other than at relatively small values where the edges of Minor Urban roads appear to be in the worst condition, there is not much difference on the other classes. Figure 73 shows the cumulative distribution of ECI values by class, which again shows how much better the edges of A class roads are.

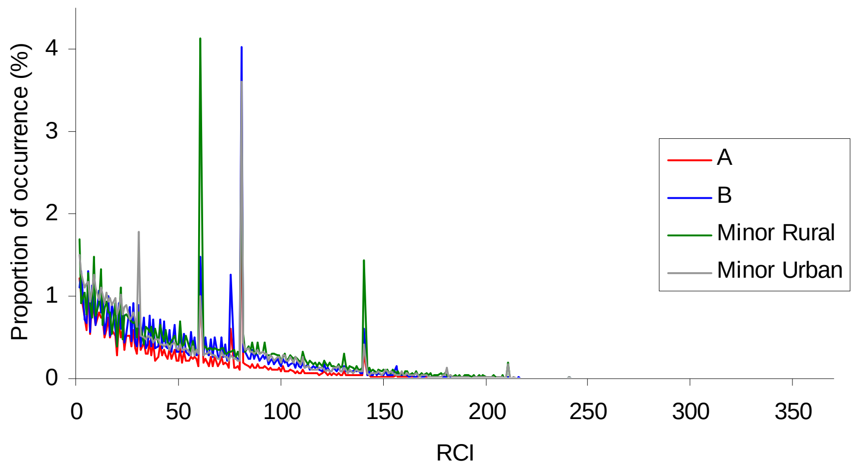


Figure 71: Distribution of RCI values on A, B, Minor Rural and Minor Urban roads.

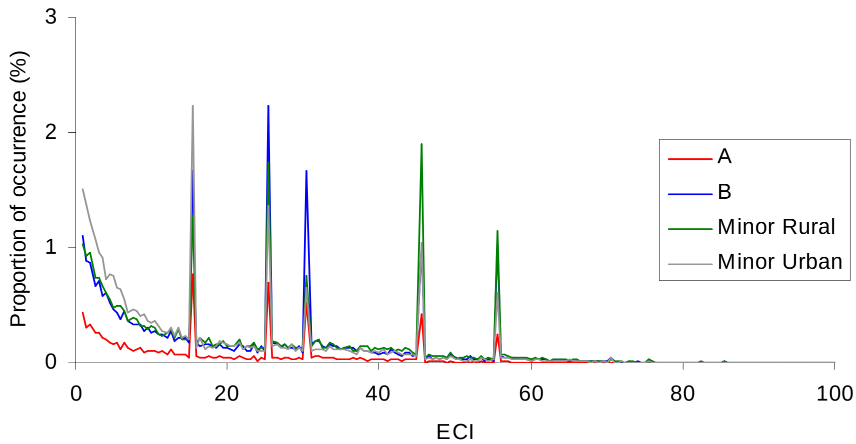


Figure 72: Distribution of un-weighted ECI values on A, B, Minor Rural and Minor Urban roads.

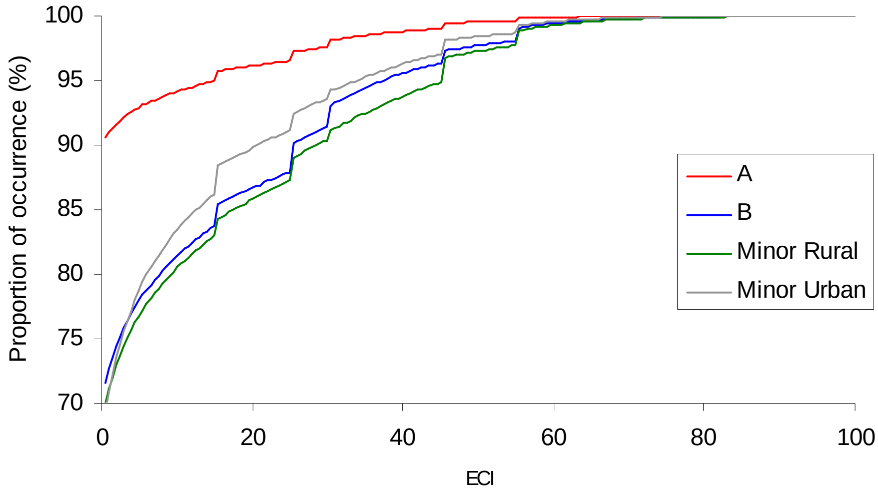


Figure 73: Cumulative distribution of unweighted ECI values on A, B, Minor Rural and Minor Urban roads.

Figure 74 shows the distribution of Extended RCI scores by class for the dataset employed in the development of the Extended RCI. The Extended RCI has been calculated using the proposed Revised RCI settings, with the addition of ADFD incorporated as family group with the rutting, and the weighted (0.5 weighting) ECI value. Comparing this with Figure 71 shows the effect of changing from the current to the Extended RCI. Figure 75 shows the distribution of the current RCI values, ECI values and Extended RCI values on A roads only. This shows that there is not much contribution from the ECI. Figure 76 shows the distribution of the current RCI values, ECI values and Extended RCI values on Minor Rural roads only. Comparing the plots we can see that not only was the RCI higher on Minor Rural roads, but the ECI, and its effect on the Extended RCI, is much higher on Minor Rural roads, where edge deterioration might be expected, than on A roads, where Edge Deterioration is less likely to occur.

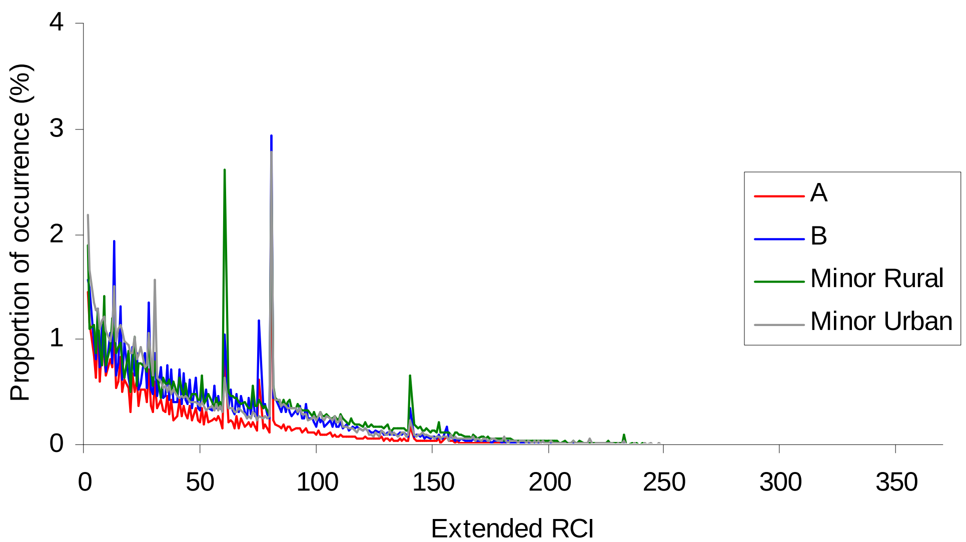


Figure 74: Distribution of Extended RCI values.

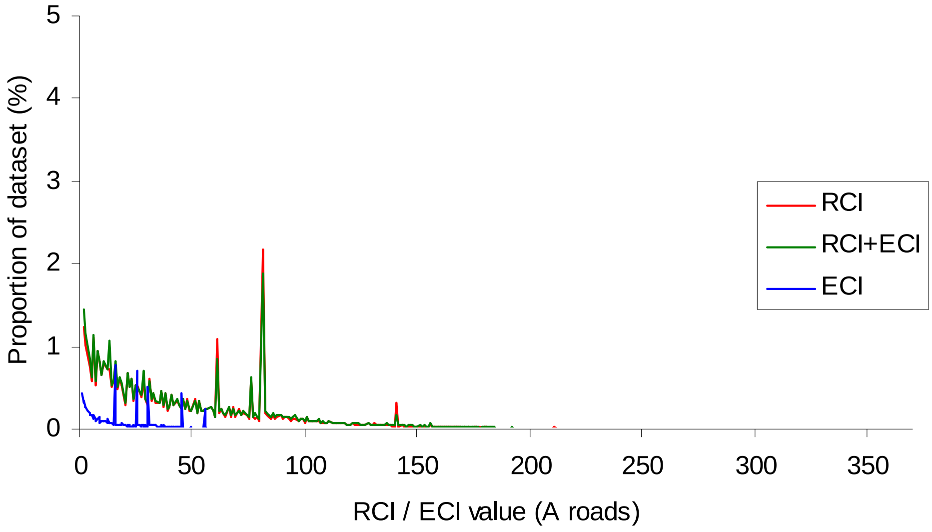


Figure 75: Distribution of unweighted ECI, RCI and Extended RCI values on A roads only.

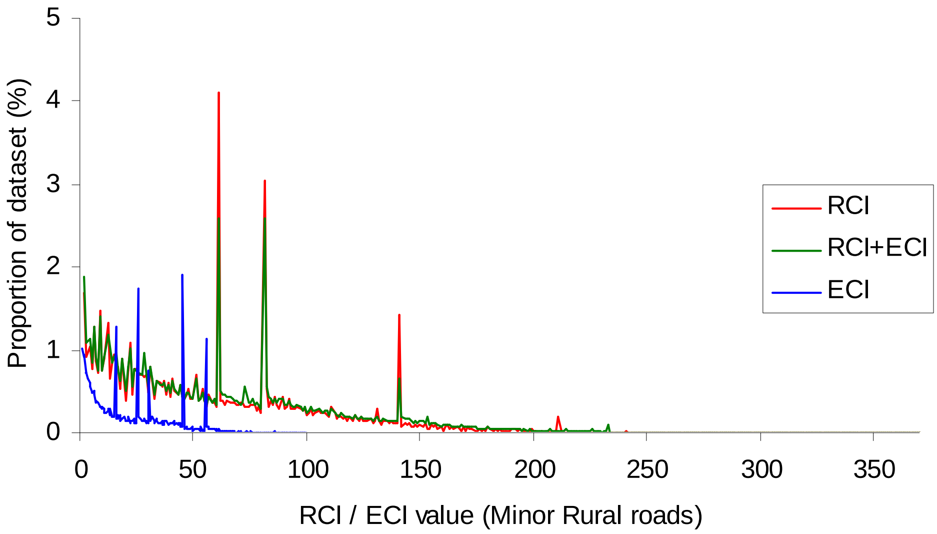


Figure 76: Distribution of unweighted ECI, RCI and Extended RCI values on Minor Rural roads only.

8 Conclusions and Recommendations

8.1 The Revised RCI

Investigations have been carried out in this work to assess the behaviour of the SCANNER RCI on the local road network. These have included both an assessment at the site level and consultation with engineer's opinions (using a workshop), and investigation at the network level (using a data set covering over 9000km of the local road network). These assessments have shown that the methodology employed in the SCANNER RCI to assess pavement condition is generally sound, but there is a need to modify a number of the thresholds and weightings employed within the RCI.

As a result, a revised set of weightings and thresholds have been proposed, as summarised in Table 52. These revisions to the RCI result in the maximum score for any subsection of to reduced from 370 to 315 on A or B roads, from 370 to 290 for rural C or U class roads, and from 370 to 270 on urban C or U class roads.

	Units	Class	Defect Value T_L	Weight below T_L	Defect Value T_U	Weight above T_U	Importance	Reliability	RxI
Rutting	mm	**A, B, C, U**	10	0	20	100	1	1	1
3mLPV*	mm^2	**A**	4	0	10	100	0.8	1	0.8
		B	5	0	13	100	0.8	1	0.8
		C	7	0	17	100	0.8	1	0.8
		U	8	0	20	100	0.8	1	0.8
10mLPV*	mm^2	**A**	21	0	56	100	0.8	1	0.8
		B	27	0	71	100	0.8	1	0.8
		C	35	0	93	100	0.8	1	0.8
		U	41	0	110	100	0.8	1	0.8
Wheeltrack cracking	%	REMOVED FROM RCI							
Whole carriageway cracking	%	**A, B, C, U**	0.15	0	2	100	1	0.6	0.6
Texture	mm	**A**	0.4	100	0.8	0	0.75	1	0.75
		B	0.3	100	0.6	0	0.75	1	0.75
		C, U (urb)	0.3	100	0.6	0	0.3	1	0.3
		C, U (rur)	0.3	100	0.6	0	0.5	1	0.5

Table 50: Recommended SCANNER RCI Thresholds and weighting factors. ****Only the maximum of the 3 or 10m LPV shall be included in the RCI calculation at any given 10m subsection*.**

The effect that these new thresholds and weighting have on the values of the RCI reported on the network is shown in Figure 77 and Figure 78 which show the proportions by class of Red, Amber and Green found using the existing and revised RCI settings respectively. When moving from the current to the revised RCI settings it can be seen that the amount of Red reported on all classes decreases. This decrease is largest on B roads, where more than half of the roads which were Red are now no longer Red. The reasons for this change are the introduction of separate LPV reporting thresholds for 3m and 10m LPV, the use of an LPV family, and the removal of wheeltrack cracking. The proposed increase in weighting given to texture on B roads does not have a huge effect, and is more than counteracted by the other changes. Most classes (except A roads) also show an increase in Green lengths. The change in the handling of LPV data is important here, and more than counteracts the changes in the rut depth thresholds, which mean that more C and U roads now fall above T_L for rut depth.

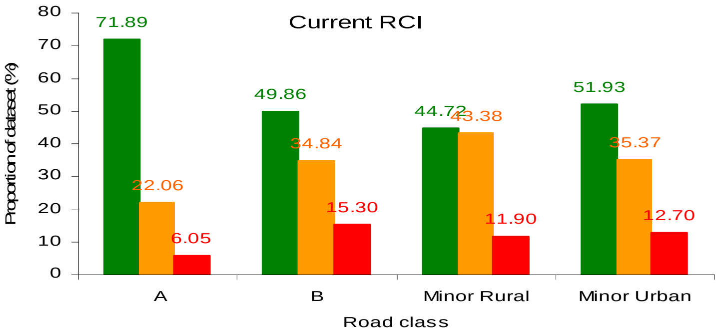


Figure 77: Proportions of Red, Amber and Green by road class using current RCI on new parameter dataset.

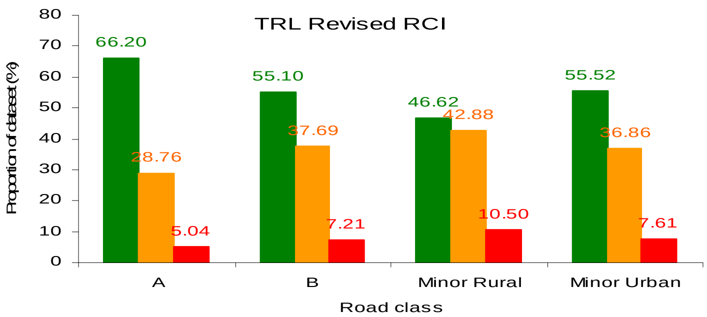


Figure 78: Proportions of Red, Amber and Green by road class using current RCI on new parameter dataset (detailed in Section 3.2.16).

8.2 The Extended RCI

The research programme has proposed a number of new parameters to assist the engineer in the assessment of pavement condition. It is proposed that these be included in the RCI, to be reported as an Extended RCI. Work has been carried out to investigate the behaviour of these parameters on the network, so that suitable thresholds and weightings can be proposed. However, this work has not attempted to validate the results against “ground truth” such as engineer’s opinions.

It is proposed that the Extended RCI be calculated through the incorporation of transverse unevenness (ADFD) as a family group with rutting, and by adding an Edge Condition Indicator (ECI) calculated using the set of thresholds defined in Table 53. Both the ADFD and ECI will be weighted in the calculation of the Extended RCI, at 0.7 and 0.5 respectively.

Figure 79 shows the proportions by class of Red, Amber and Green found using the proposed Extended RCI settings. Comparison of Figure 78 with Figure 79 shows that the extended RCI deliver a larger proportion of Red lengths. This is due to the introduction of the ADFD and ECI values. The new parameters have very little effect on the A roads, as would be expected, but more of an effect on the other classes, particularly on the Minor classes, and particularly in Rural areas. Again, this is to be expected, as Rural Minor roads are the ones on the network most likely to suffer from Edge Deterioration.

	A		B		Minor Rural		Minor Urban	
Parameter	**T_L**	**T_U**	**T_L**	**T_U**	**T_L**	**T_U**	**T_L**	**T_U**
Edge Step Level 1	**7**	**20**	**7**	**20**	**7**	**20**	**7**	**20**
Edge Step Level 2	**0**	**5**	**0**	**5**	**0**	**5**	**0**	**5**
Edge Roughness	**0.2**	**0.3**	**0.2**	**0.3**	**0.3**	**0.5**	**0.3**	**0.5**
Transverse Variance	**100**	**250**	**100**	**250**	**100**	**250**	**100**	**250**
ADFD	**0.04**	**0.07**	**0.04**	**0.07**	**0.04**	**0.07**	**0.04**	**0.07**

Table 51: Proposed values for T_L and T_U for use with new parameters.

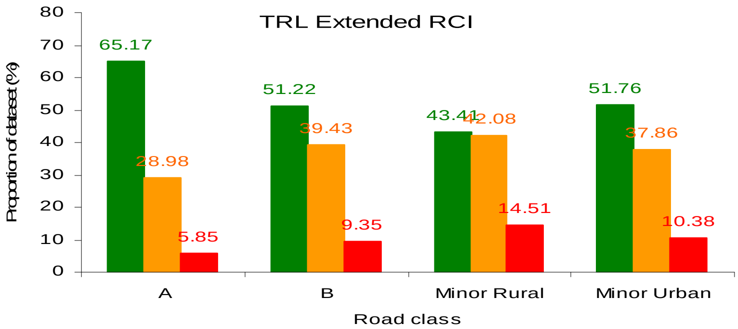


Figure 79: Proportions of Red, Amber and Green by road class using proposed Extended RCI.

8.3 Obtaining and working with the RCI

8.3.1 The Network

The data used to calculate the RCI is delivered by the SCANNER survey. Because the survey does not cover the whole network each year there is a risk that the selection of the length surveyed will have an adverse affect on the accuracy of the value of the RCI, which may be a particular problem on lower classes of road. Work has been carried out to assess the effect of the proportion of the network surveyed on the resultant RCI, in order to derive recommendations for the proportion of the network to survey. This work has suggested that, to obtain an RCI with 95% confidence that the obtained RCI lies within ±0.75 of the true RCI would require the following (approximate) randomly surveyed lengths:

- For a 50km network: 100% survey, or 50km
- For a 200km network: 50% survey, or 100km
- For a 400km network: 30% survey, or 120km
- For a 1000km network: 15% survey, or 150km
- For a 2000km network: 10% survey, or 200km

8.3.2 Benchmarks

A network RCI is reported by each LA. Because of the differing natures of the networks it would be desirable to establish a set of benchmarks that assist in comparing similar Authorities. Work has been carried out to determine if it would be possible to establish such benchmarks. Unfortunately the work has been unable to identify particular characteristics that would enable us to differentiate between different types of LA. This is due to too much variation in the data that cannot be explained by the explanatory variables that are available.

8.3.3 Trajectories

Currently LAs have limited experience with the use of the RCI in planning maintenance. There is even less experience in the establishment of programmes of work that would enable an LA to maintain the network to an expected level of RCI. Therefore a simple trajectory tool has been developed to assist local authorities in exploring the possible consequences on the RCI of applying different maintenance scenarios. This is based on the initial condition of the network and simple assumptions about the effects of deterioration and maintenance on the RCI. Basic tests of this tool have indicated that the behaviour is reasonable, but the model has not been subject to extensive testing to validate the parameter values used.

8.4 Recommendations for Further Work

At the conclusion of this work we able to suggest the following areas for further development:

- This work has proposed a number of revisions to the RCI. It is recommended that the effectiveness of these be reviewed once there has been sufficient experience in the use of the revised RCI (e.g. 12 months).
- The proposals for the Extended RCI have been based on a limited dataset, and without comparison with the experiences of engineers in the assessment of the specific defects assessed within the it (e.g. edge deterioration). Again it is recommended that the effectiveness of the Extended RCI be reviewed once there has been sufficient experience in the use of the revised RCI (e.g. 12 months).
- The current proposals for the Extended RCI do not include all features that will be provided by the 2007- SCANNER survey (e.g. bump measure). The incorporation of these features should be considered once sufficient data becomes available.
- The workshop carried out during the assessment of the RCI was a successful way of relating the opinions of engineers with the reported RCI. However, it also showed the benefits of demonstrating to engineers how the RCI works and how it could be used to assist in their maintenance planning. The continuation of such workshops, as training for engineers, could offer significant benefits to Local Authorities.
- The RCI trajectory model has been developed on the basis of a number of assumptions with regard to the projection of deterioration. It is recommended that, as more information becomes available about changes in RCI values over time and with maintenance, further work is undertaken to develop the projection and maintenance algorithms.

- The RCI (and extended RCI) provide a single measure of condition. However, the consultation showed that engineers have to consider a wide range of needs when maintaining their networks, including safety, structural and user needs. There is potential to develop the RCI approach to deliver further indicators targeted at these areas and hence assist engineers and the DfT in assessing the capability of the network in meeting its diverse range of needs. It is recommended that further work be carried out to consider the potential of these additional indicators.

Acknowledgements

The work described in this report was carried out in the Infrastructure & Environment Division of TRL Limited. The authors are grateful to Helen Viner who carried out the technical review and auditing of this report.

The authors would like to thank the SCANNER RCIWG members for their valuable contributions and guidance throughout the project, the participants of the Workshop, and Mr Simon Mitchell of Bracknell Forest Borough Council who assisted with the selection of the workshop sites.

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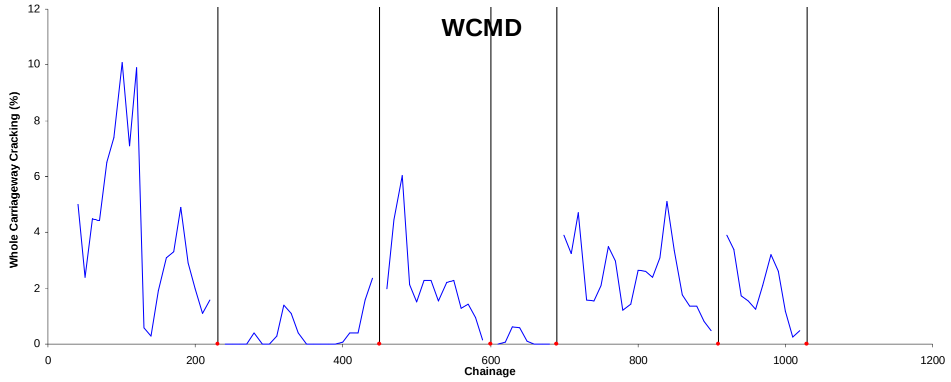
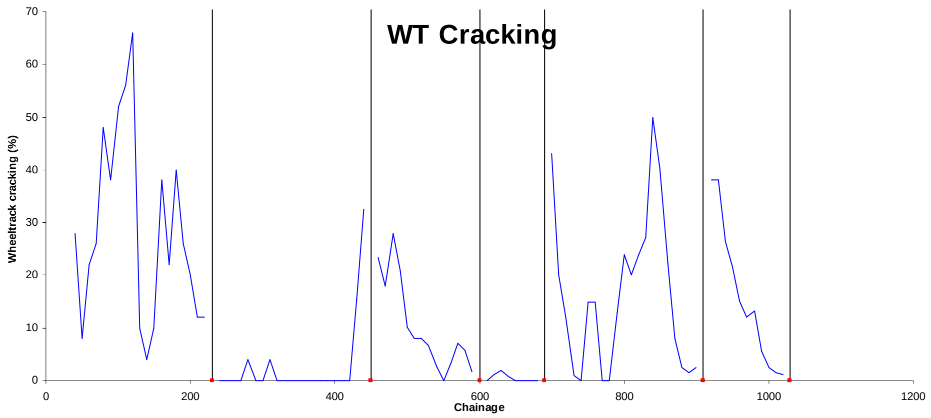
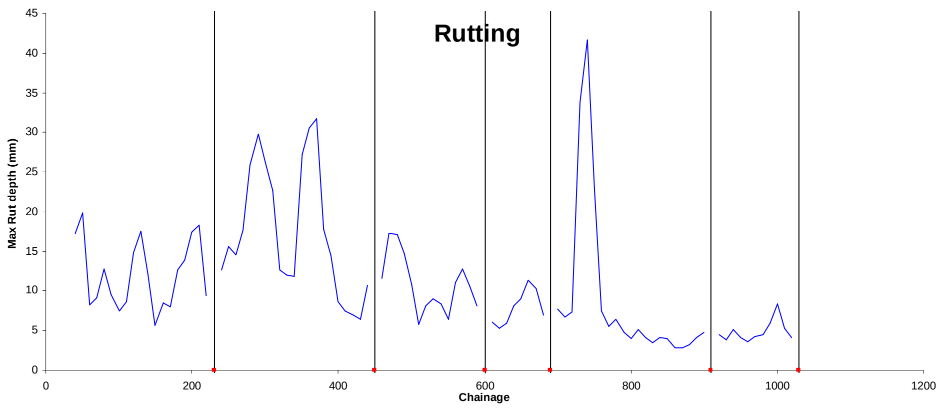
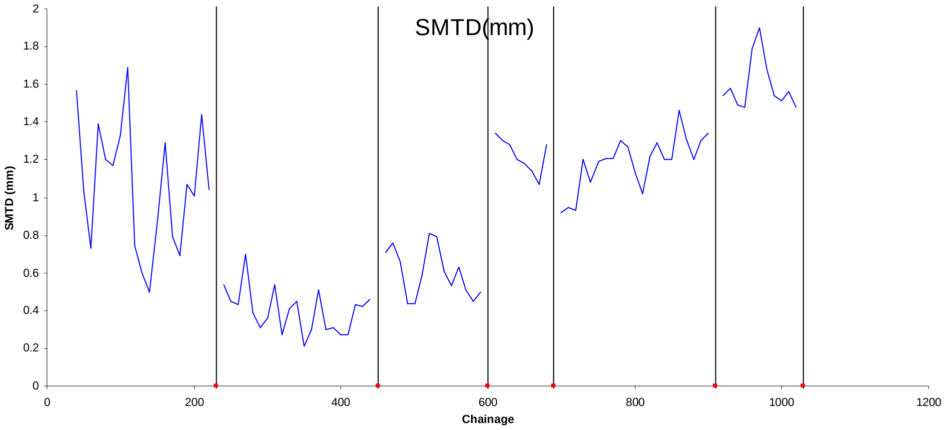
Appendix A. Workshop

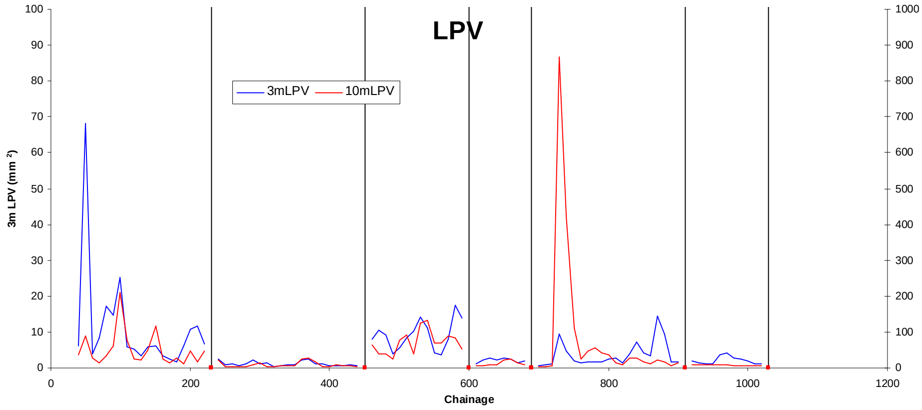
The following figures present the raw SCANNER data for the workshop sites in the order 6, 5, 1, 2, 3, 4.

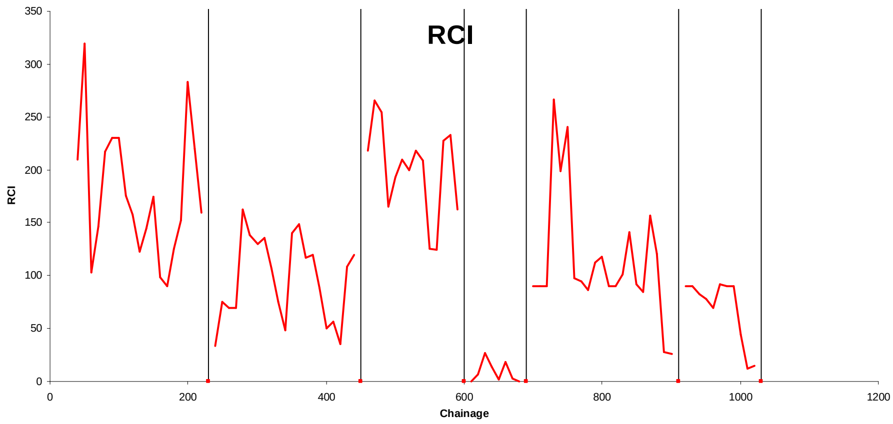







SMTD(mm)
SMTD (mm)
Chainage


LPV
3mLPV
10mLPV
3m LPV (mm²)
Chainage


RCI
RCI
Chainage

Name	Representing
Jonathon Ullmer	West Sussex
Naeem Ahad	Bromley
Alistair Gow	SCANNER RCIWG / SRMCS
Peter Trumper	Jacobs / Kent
Peter Rossiter	Hampshire
Philip Churchward	Hampshire
Claire Read	Surrey CC

Table 52: TRL SCANNER RCI Workshop attendees.

Site	Rating	Maintenance need	Comments
1a	127	Medium	Local reconstruction. Deformation Poor reinstatement at junction Failing patches.
1b	35		Worn surface dressing Minor deformation Poor reinstatement at junction
2	11	5-10yrs	Minor chip loss Minor edge cracking 1 crack – might get worse over next few years - monitor
3	24	Low priority	Patches are OK Poor texture at junction Carriageway in good condition Some off carriageway defects present
4	50	Monitor	Longitudinal crack Verge not providing adequate support for edge of road Kerb failure Like Site 3, but worse Would haunch or reinforce edge if funds available
5	149	High – 12 months	Dangerous levels of rutting in NS and OS Cracking Surface worn and fretted.
6	151	High – 12 months	Fretting at covers Patches Rutting – structural not surface Cracking

Table 53: Engineers opinions on sites visited during workshop

Appendix B. Existing RCI Definition

		units	Defect Value T_L	Weight below T_L	Defect Value T_U	Weight above T_U	Importance	Reliability	**RxI**
A, B	Rutting	mm	10	0	20	100	0.9	1	**0.9**
C, U (urb)			12	0	25	100	0.9	1	**0.9**
C, U (rur)			15	0	30	100	0.9	1	**0.9**
A, B	3m LPV	mm^2	4	0	10	100	0.8	1	**0.8**
C, U (urb)			7	0	17	100	0.8	1	**0.8**
C, U (rur)			15	0	25	100	0.8	1	**0.8**
A, B	10m LPV	mm^2	21	0	56	100	0.6	1	**0.6**
C, U (urb)			45	0	90	100	0.6	1	**0.6**
C, U (rur)			45	0	130	100	0.6	1	**0.6**
A, B	Texture	mm	0.3	100	0.6	0	0.5	1	**0.5**
C, U (urb)			0.3	100	0.6	0	0.5	1	**0.5**
C, U (rur)			0.3	100	0.6	0	0.5	1	**0.5**
A, B	Whole carriageway cracking	%	0.15	0	2	100	1	0.5	**0.5**
C, U (urb)			0.15	0	2	100	1	0.5	**0.5**
C, U (rur)			0.15	0	2	100	1	0.5	**0.5**
A, B	Wheel track cracking	%	0.5	0	5	100	0.8	0.5	**0.4**
C, U (urb)			0.5	0	5	100	0.8	0.5	**0.4**
C, U (rur)			0.5	0	5	100	0.8	0.5	**0.4**

Table 54: Currently used SCANNER RCI Thresholds and weighting factors

Note that, in its current definition, the RCI classifies each 10m subsection of network as Red, Amber or Green, and reports the proportion Red as the BV Value for the Authority. The definitions of Red, Amber and Green are as follows:

- Red – lengths in poor overall condition which are likely to require planned maintenance soon (i.e. within a year or so) on a “worst first basis;
- Amber – lengths where some deterioration is apparent which should be investigated to determine the optimum time for planned maintenance treatment;
- Green – lengths where the carriageway is generally in a good state of repair. (DfT website, 2005)

Appendix C. Calculation of Crack Intensity

To calculate carriageway cracking the carriageway is divided into an array of 200mm by 200mm square boxes, as shown in Figure 80. If any box contains a crack then the entire area of the box is counted (grey shaded squares in Figure 80) as being affected by cracking. The reported carriageway cracking parameter is the proportion of boxes in any 10m length containing one or more detected cracks (Figure 80 only shows a 5m length, but the principle holds).

Wheeltrack cracking is calculated separately for each wheeltrack. This is calculated by counting the number of boxes containing cracks in the wheeltracks in a way similar to carriageway cracking. However an important difference here is that instead of the boxes being 200mm square, they are 200mm long, but 800mm wide, encompassing the entire wheeltrack, and indicated by the red lines in Figure 80. Any of these boxes containing one or more cracks (which must also meet some additional criteria regarding orientation of crack and length of crack in and out of wheeltrack) is counted as being affected by wheeltrack cracking (cross hatched squares in Figure 80). Each wheeltrack has 50 boxes in a 10m length.

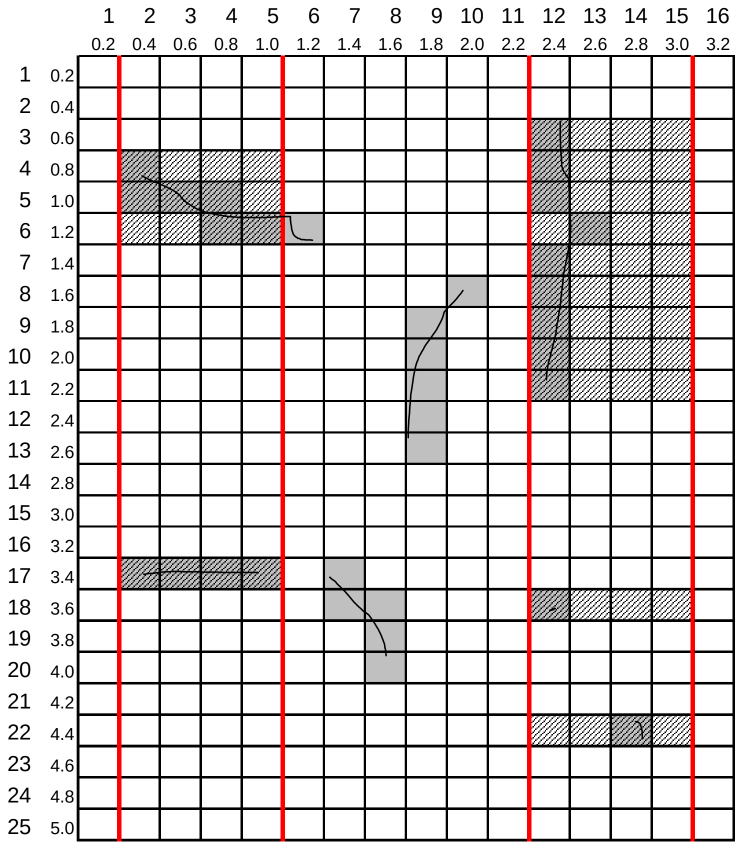


Figure 80:Illustration of principles behind calculation of carriageway and wheeltrack cracking.

For a typical SCANNER survey, of 3.2m width, there are 16 box widths across the width of the pavement, and 50 box lengths in each 10m reporting subsection length. This makes a total of 800 boxes for calculating carriageway cracking.

If 8 of these 200mm square boxes contains a detected crack then 1% of the total are of the 10m subsection would be reported as being cracked. Each box affected contributes 0.125% to the total crack area. T_L for carriageway cracking is 0.15%, and T_U is 2%. These are breached by 2 boxes (0.25%) and 16 boxes (2%) respectively.

For wheeltrack cracking there are 50 boxes in each wheeltrack. Each affected box therefore contributes 2% to the total wheeltrack cracking reported. T_L for wheeltrack cracking is 0.5%, and T_U is 5%. These are breached by 1 boxes (2%) and 3 boxes (6%) respectively.

The example shown in Figure 80 (which is for a 5m rather than a 10m length, but the principles are the same) would have 33 boxes containing carriageway cracking out of a total of 400, 4 boxes of nearside wheeltrack cracking, and 11 boxes of offside wheeltrack cracking.

Carriageway cracking	-	33/400	= 8.25%
Nearside wheeltrack cracking	-	4/25	= 16%
Offside wheeltrack cracking	-	11/25	= 44%

Only the maximum of the two wheeltracks would contribute to the RCI, which is 44% from the offside in this case. The carriageway cracking of 8.25% is above T_U (2%), and so would score a maximum of 50 points for the RCI. The offside wheeltrack cracking of 44% is above T_U (5%) and so would score a further 40 points towards the RCI. Therefore the total contribution to the RCI of the cracks shown would be 90 points.

Appendix D. Authority Clustering results

Subgroup	Name	Region	% BU
Deep Rural County Council	Shropshire	West Midlands	17.6%
	North Yorkshire	Yorkshire + Humberside	19.7%
	Northumberland	North East	20.1%
	Cumbria	North West	20.5%
	Lincolnshire	East Midlands	20.7%
Rural County Council	Oxfordshire	South East	25.7%
	Cambridgeshire	East	26.6%
	Dorset	South West	26.9%
	Leicestershire	East Midlands	27.4%
	Gloucestershire	South West	27.5%
	Wiltshire	South West	28.3%
	Devon	South West	28.9%
	Durham	North East	29.2%
	Cornwall	South West	29.2%
	Cheshire	North West	29.5%
	Nottinghamshire	East Midlands	30.4%
	Hampshire	South East	30.4%
	Norfolk	East	31.9%
	Warwickshire	West Midlands	32.0%
	Essex	East	33.1%
	Worcestershire	West Midlands	33.1%
	Somerset	South West	33.1%
	Buckinghamshire	South East	34.0%
	West Sussex	South East	34.1%
	Bedfordshire	East	36.3%
	Northamptonshire	East Midlands	36.7%
Semi Rural County Council	Derbyshire	East Midlands	39.1%
	Suffolk	East	39.1%
	East Sussex	South East	40.2%
	Staffordshire	West Midlands	40.9%
	Kent	South East	43.0%
	Hertfordshire	East	53.1%
	Lancashire	North West	53.2%
	Surrey	South East	59.0%
Central London Borough Council	Camden	London	100.0%
	City of London	London	100.0%

	Hammersmith & Fulham	London	100.0%
	Islington	London	63.7%
	Kensington & Chelsea	London	100.0%
	Lambeth	London	100.0%
	Southwark	London	100.0%
	Tower Hamlets	London	100.0%
	Wandsworth	London	100.0%
	Westminster	London	100.0%
Inner London Borough Council	Barking & Dagenham	London	100.0%
	Brent	London	96.4%
	Ealing	London	100.0%
	Greenwich	London	92.3%
	Hackney	London	100.0%
	Haringey	London	100.0%
	Lewisham	London	100.0%
	Merton	London	100.0%
	Newham	London	100.0%
	Richmond upon Thames	London	100.0%
	Waltham Forest	London	99.3%
Outer London Borough Council	Barnet	London	99.4%
	Bexley	London	91.4%
	Bromley	London	96.7%
	Croydon	London	97.9%
	Enfield	London	91.1%
	Harrow	London	100.0%
	Havering	London	100.0%
	Hillingdon	London	89.5%
	Hounslow	London	100.0%
	Kingston-upon-Thames	London	100.0%
	Redbridge	London	94.3%
	Sutton	London	100.0%
Semi Rural Metropolitan Borough Council	Wakefield	Yorkshire + Humberside	36.0%
	Solihull	West Midlands	40.6%
	Barnsley	Yorkshire + Humberside	43.5%
	Gateshead	North East	47.9%
	Doncaster	Yorkshire + Humberside	53.9%
	Sunderland	North East	55.9%
	Rotherham	Yorkshire + Humberside	59.6%

Semi Urban Metropolitan Borough Council	North Tyneside	North East	60.8%
	Knowsley	North West	62.5%
	Coventry	West Midlands	64.1%
	Calderdale	Yorkshire + Humberside	65.8%
	Leeds	Yorkshire + Humberside	67.7%
	St Helens	North West	68.8%
	Kirklees	Yorkshire + Humberside	68.9%
	Sheffield	Yorkshire + Humberside	75.3%
	South Tyneside	North East	75.9%
	Bolton	North West	78.3%
Urban Metropolitan Borough Council	Oldham	North West	82.4%
	Bradford	Yorkshire + Humberside	84.5%
	Salford	North West	85.9%
	Wirral	North West	86.6%
	Newcastle upon Tyne	North East	86.7%
	Stockport	North West	87.1%
	Wigan	North West	89.9%
	Rochdale	North West	90.5%
	Sefton	North West	94.8%
Very Urban Metropolitan Borough Council	Liverpool	North West	96.3%
	Sandwell	West Midlands	96.4%
	Dudley	West Midlands	97.1%
	Walsall	West Midlands	97.3%
	Tameside	North West	97.8%
	Birmingham	West Midlands	97.8%
	Trafford	North West	97.9%
	Manchester	North West	97.9%
	Bury	North West	99.3%
	Wolverhampton	West Midlands	99.8%
Deep Rural Unitary Authority	Telford & Wrekin	West Midlands	6.9%
	Milton Keynes	South East	8.2%
	Isle of Wight	South East	12.4%
	Herefordshire	West Midlands	15.2%
	Redcar & Cleveland	North East	19.2%
Rural Unitary Authority	East Riding of Yorkshire	Yorkshire + Humberside	23.2%
	Rutland	East Midlands	25.3%
	Halton	North West	27.9%
	Peterborough	East	31.5%
	West Berkshire	South East	32.9%

	Thurrock	East	33.8%
	North Lincolnshire	Yorkshire + Humberside	35.3%
	Darlington	North East	36.0%
	Bracknell Forest	South East	37.6%
Semi Rural Unitary Authority	South Gloucestershire	South West	43.6%
	North East Lincolnshire	Yorkshire + Humberside	44.2%
	Swindon	South West	48.2%
	North Somerset	South West	49.6%
	Wokingham	South East	50.1%
	Windsor & Maidenhead	South East	53.0%
	Bath & N E Somerset	South West	54.0%
	Hartlepool	North East	54.8%
	Stockton-on-Tees	North East	56.6%
Semi Urban Unitary Authority	Medway Towns	South East	61.7%
	Poole	South West	62.4%
	Warrington	North West	63.8%
	York	Yorkshire + Humberside	64.6%
	Middlesbrough	North East	66.7%
	Blackburn with Darwen	North West	69.5%
	Bournemouth	South West	77.9%
Urban Unitary Authority	Derby	East Midlands	81.1%
	Torbay	South West	82.5%
	Bristol	South West	83.7%
	Southampton	South East	87.8%
	Portsmouth	South East	88.4%
	Brighton & Hove	South East	89.9%
	Slough	South East	90.2%
	Nottingham	East Midlands	93.0%
	Luton	East	93.4%
	Plymouth	South West	94.0%
	Southend-on-Sea	East	94.6%
Very Urban Unitary Authority	Stoke-on-Trent	West Midlands	96.2%
	Blackpool	North West	96.6%
	Leicester	East Midlands	99.1%
	Reading	South East	100.0%
	Kingston-upon-Hull	Yorkshire + Humberside	100.0%

Appendix E. User guide for TRL RCI Projection Tool

User guide for TRL RCI Projection Tool

1. Introduction

The TRL RCI Projection Tool was developed in order to show trends in the deterioration of a network under different maintenance scenarios over a five year period. The model is based on information about the initial condition of the network and simple assumptions about the effects of deterioration and maintenance. It is written as a Macro based in Microsoft Excel and has a simple user interface that allows easy import of data and alteration of necessary variables.

The projection was developed by looking at trends in the change of physical measures of road condition such as rutting and texture and using these to create a probability distribution that reflects the change in RCI value associated with the change in the physical parameter. The macro has been supplied with three rates of deterioration in order that the differences between networks with high and low traffic loads can be better simulated.

It should be noted that, while basic tests indicate the behaviour is reasonable, the model has not been subject to extensive testing to validate the values of the variables used. Therefore, a great deal of variables are open for the user to define, this allows to tool to be better customised to each network.

It is recommended that each user establish appropriate values based on their local experience, and use the results with caution.

2. System Requirements

Operating system: Microsoft Windows XP
Disk Space: 1 MB
Application: Microsoft Excel 2002 or later

3. Security Settings

To allow the macro to run the security settings in Microsoft Excel must be set to medium or low. This can be done by selecting “Tools”- “Macro”-“Security” and setting the appropriate level. It may then be necessary to re-open the Projection Tool and, if security is on the medium setting, select “Enable Macros” when the prompt box appears asking whether to allow Macros.

4. Analysis Details

Figure 1 is a screenshot of the Analysis Details worksheet; this is the main screen from which files can be imported, maintenance lengths and efficiencies be altered, and the projection algorithm run.

Maintenance lengths set the amount of the network to be maintained whilst maintenance efficiencies control the targeting and results of the maintenance. It is recognised that in maintaining a length of road the focus will be on improving sections with RCI values in the red band but some parts of the length being maintained will contain sections that correspond to amber and perhaps green RCI values. The percentages under the headings “Red”, “Amber” and “Green” can be set to give the best representation of this effect on a particular network.

The reset bands take into account that the result of the maintenance will not always be to restore a section to a perfect condition. Instead, a band of values is used to represent the variable success of different types of maintenance (See 6. Setting Variables)

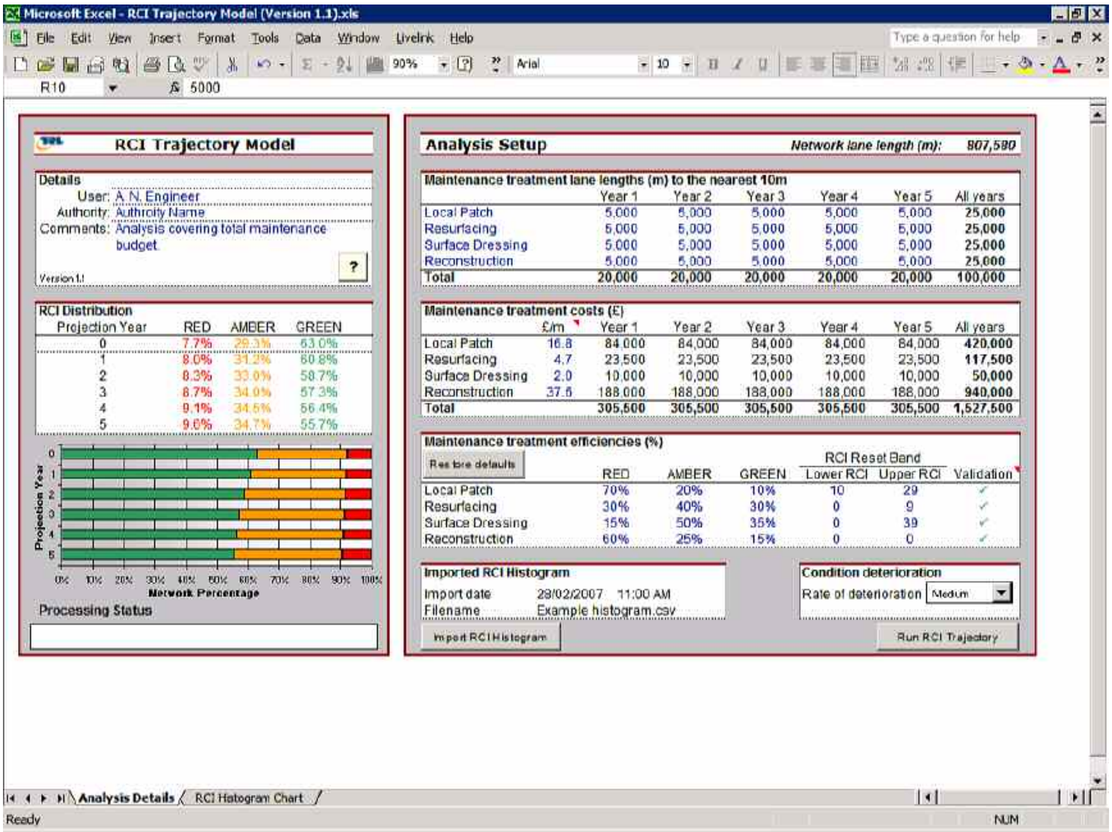


Figure 1: Analysis Details

Clicking on the help button (marked with a '?') displays instructions/reminders on using the projection tool.

5. Import Data

In order to project the changes in RCI values over five years the software requires the initial (year 0) RCI values to be imported by the user. The import file should consist of two columns, the first numbered with all the possible RCI values from 0 to 370, and the second; the frequency of roads in the network with that RCI value (see figure 2 for a section of a typical file). The file should then be saved in the .csv format.

RCI Value	Year 0
0	34265
1	1182
2	1296
3	1128
4	1497
5	970
6	813
7	1178
8	887
9	911
10	797

Figure 2: Section of Example histogram.csv

The data is imported using the following steps:

1. From the Analysis Details worksheet click on the Import RCI Histogram button at the bottom of the screen. A window will open enabling you to browse the files stored on your computer.
2. Select the file containing the initial histogram and click ok.

3. The Analysis Details worksheet should now display the name of the file and the time it was imported in the bottom right of the sheet and the network length in the top right. The RCI Distribution section (left hand side) will now show information on year 0 only and the bar chart below will match it.
4. If this doesn't happen, check that the file selected is in the correct format, is not open in any other application, and try again.

6. Setting variables

The main variable to set is the condition deterioration rate; this is done by selecting an option from the drop down list in the bottom right hand corner. The user can also specify all the details associated with maintenance of the network. This includes type of maintenance, efficiency, length and cost. These are found on the right-half of the screen under the title Analysis Setup. Further space is provided to include extra details about the analysis, this is in the top left of the screen marked Details. All the variables which can be adjusted by the user are indicated on the spreadsheet by the use of a blue font.

The Details that can be included are the **User**, **Authority** and any **additional comments**. These are inputted by simply selecting the appropriate cell and typing. Similarly **Maintenance Treatment Lengths** and **Costs** are inputted by selecting the appropriate cell and entering the numbers. Treatment lengths must be entered to the nearest ten metres otherwise an error message will prompt you to re-enter the data.

Maintenance Treatment Efficiencies control the targeting of the maintenance and the effect it has on RCI score. The percentages found under the headings RED, AMBER and GREEN show where the maintenance is concentrated e.g. with the default settings 70% of Local Patch maintenance is done on lengths of the network in the red band (RCI values 100 to 370). These percentages can be altered by clicking on the appropriate cell and selecting an efficiency level from the drop down list and can be used to simulate more targeted maintenance, the validation box displays a green tick when maintenance efficiencies sum to 100% and a red cross otherwise. The **Reset bands** control the effect of the maintenance e.g. with default settings Local Patch maintenance will reset RCI values to between 10 and 29. Note that under default settings Reconstruction will reset RCI values to 0. These can be changed using the drop down menus.

The lengths used are in SCANNER lane metres, i.e. network length in lane 1. Therefore, the maintenance costs are set in £/m where 1m is one metre of lane length that has been surveyed.

Data entered by the user will be saved when the spreadsheet is saved, but the variables can be put back to the original settings by clicking on the Restore Defaults button.

7. RCI Histogram Chart

This worksheet displays the projected distribution of RCI values with and without maintenance from year 0 to year 5. The graphs are selected using the list box in the top right of the worksheet.

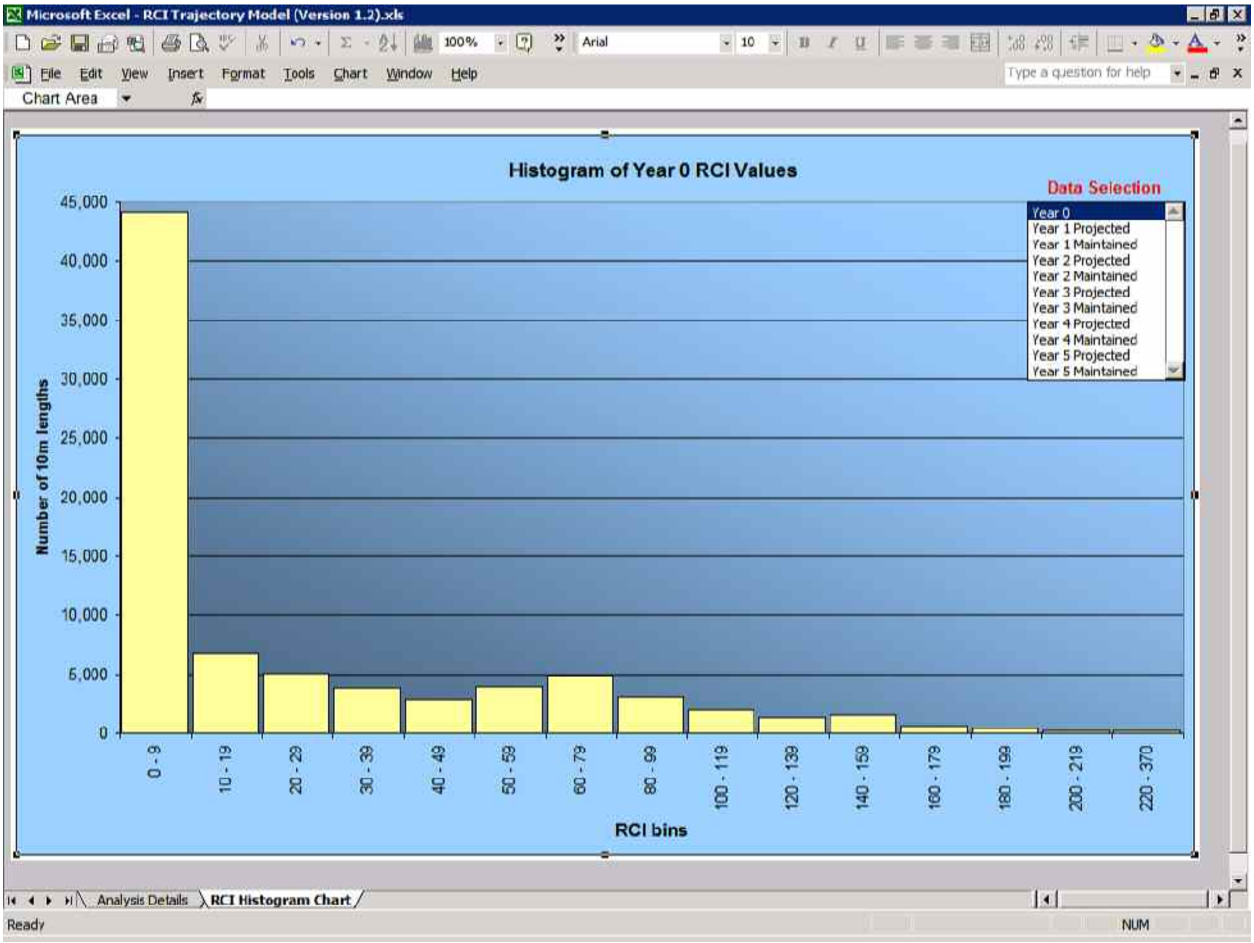


Figure 3: RCI Histogram Chart – Example Year 0 data.

8. Worked example – Example histogram.csv

In order to demonstrate the features of the projection tool you can go through this worked example using the Example histogram.csv file supplied with the software.

1. From the Analysis Details section click on the Import RCI Histogram button and select the file Example histogram.csv from the RCI Projection folder.
2. Note that the Distribution section shows the information for year 0 only (See Figure 4).
3. Click on the tab marked RCI Histogram Chart and select the year 0 option from the list (See Figure 3 above).

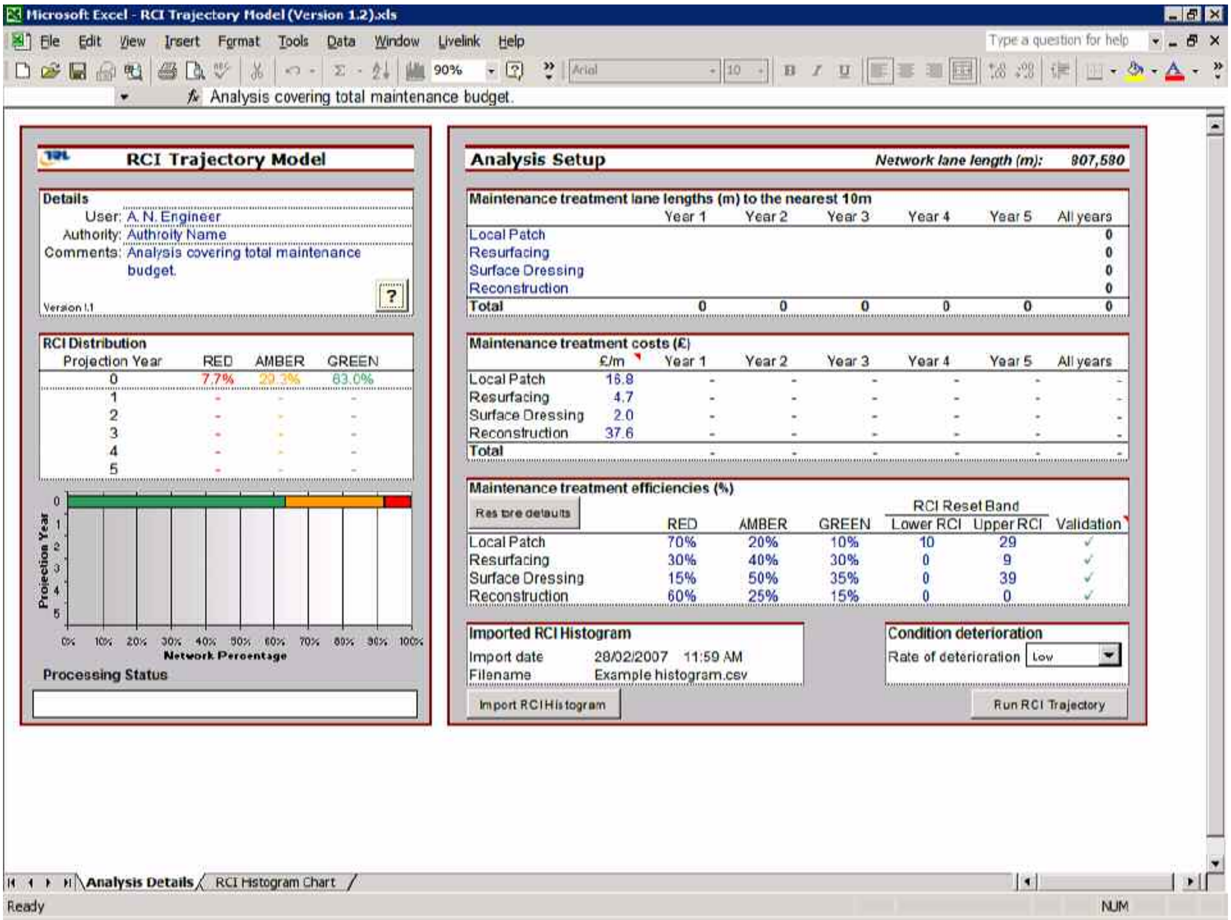


Figure 4: Example histogram.csv Year 0 data

The histogram will show the distribution of RCI values from the file imported (Figure 3 above). Note that selecting any other option from the list box produces an empty histogram as the data required for these have not been produced yet.

Now let's look at how the RCI values are projected to change without any maintenance:

4. Go back to the Analysis Details sheet by clicking on the tab.
5. Clear any data from the Maintenance Lengths section and note that the Maintenance Costs go to zero upon doing this.
6. Select the option Medium from the Condition Deterioration box and click on the Run RCI Projection button. After a few moments the Distribution screen will update to show the projected RCI values for years 1 to 5 (See Figure 5).

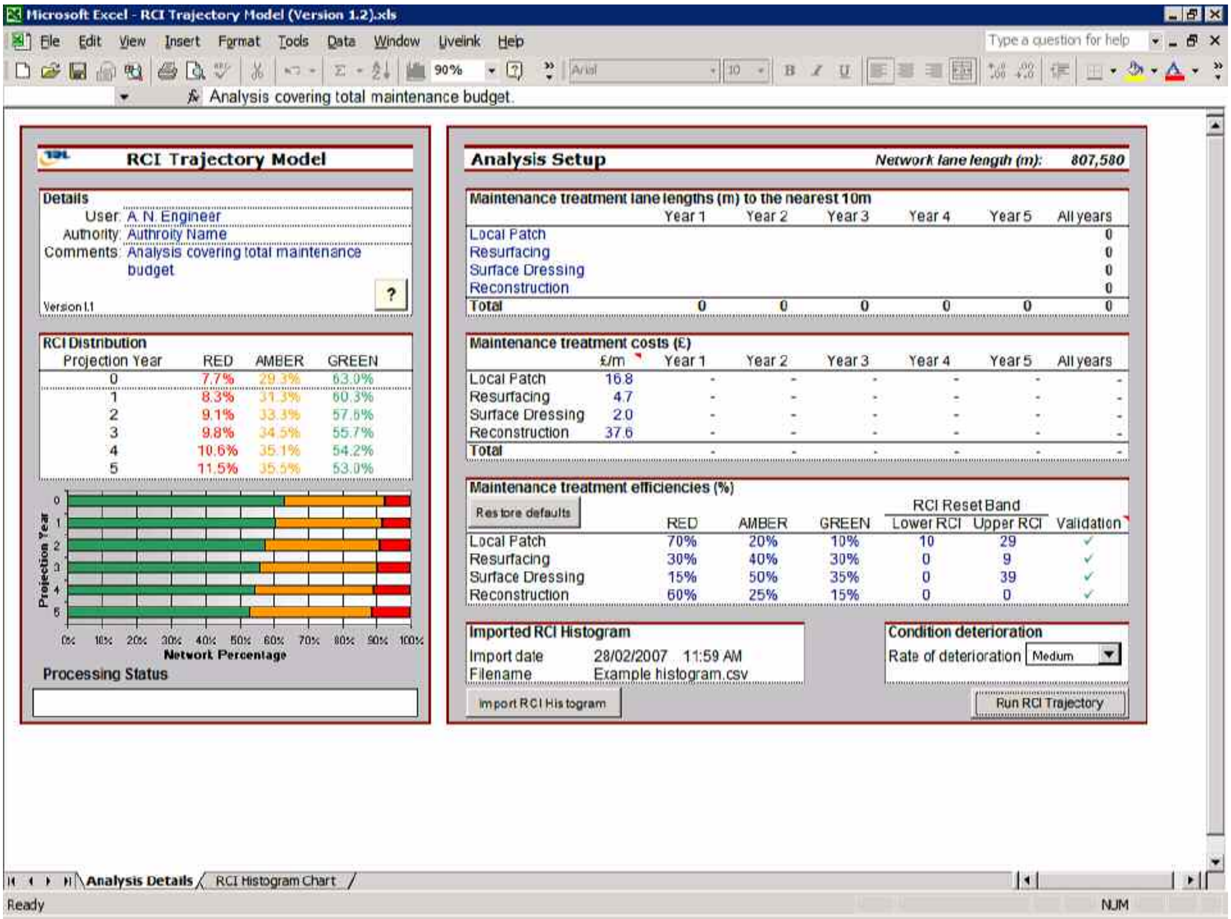


Figure 5: Five Year projection without maintenance.

7. To get a more detailed view of how the projected condition of the network has changed look again at the RCI Histogram Chart.
8. By selecting different years you can compare the level of deterioration of the network by examining the change in RCI value (See Figure 6).
9. Note that the projected and maintained histograms are the same for each year. This is because there is no maintenance set.

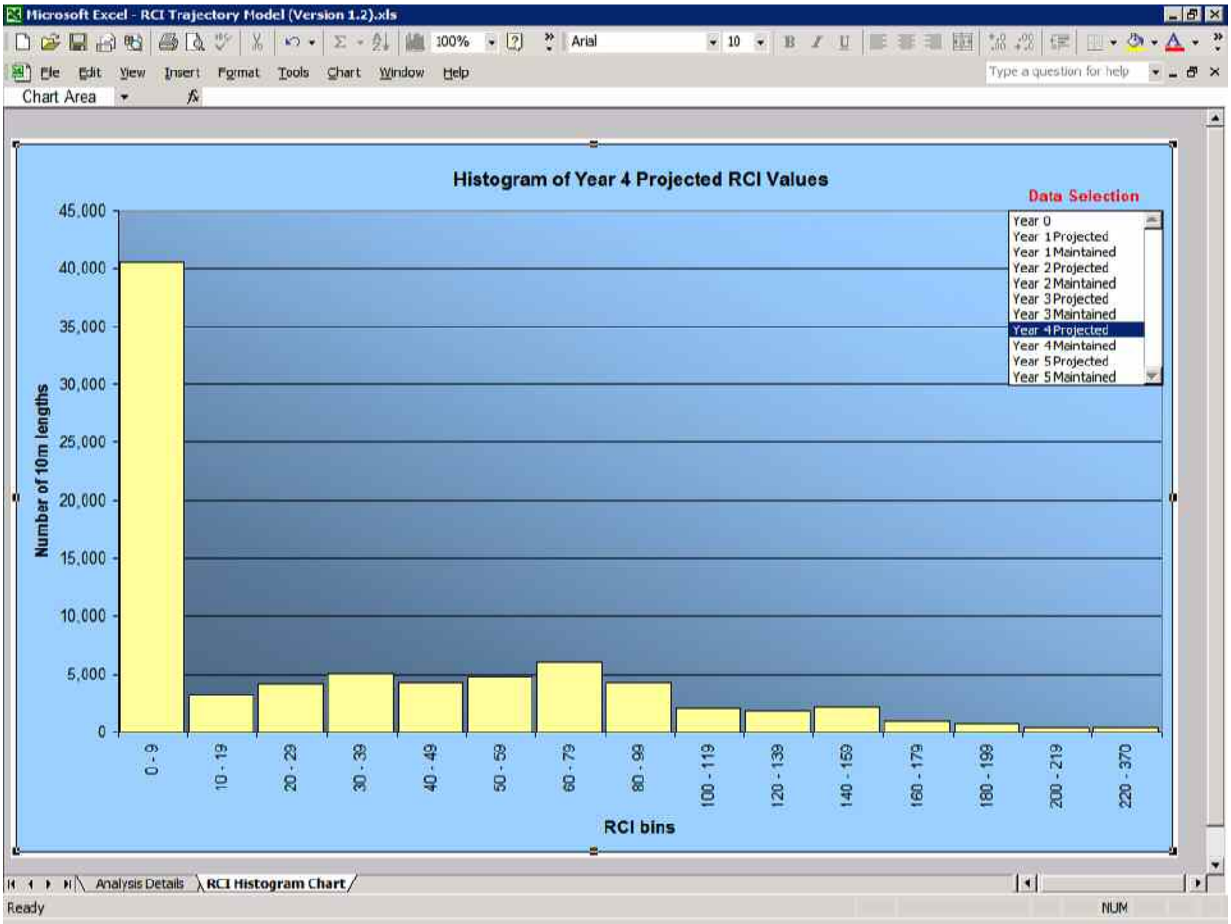


Figure 6: Example Year 4 Projection

In order to make the projection more realistic some maintenance must be added.

10. Enter the maintenance lengths as shown in the table below (Table 1).
11. Click on the Run RCI Projection button again and look at the Distribution section. It will now display an almost constant distribution of green, amber and red scores for each year of the projection (See Figure 7).
12. Look again at the RCI Histogram Charts to see the results of the maintenance.

Maintenance treatment lane lengths (m) to the nearest 10m						
	Year 1	Year 2	Year 3	Year 4	Year 5	All years
Local Patch	4,040	4,040	4,040	4,040	4,040	**20,200**
Resurfacing	8,080	8,080	8,080	8,080	8,080	**40,400**
Surface Dressing	8,080	8,080	8,080	8,080	8,080	**40,400**
Reconstruction	4,040	4,040	4,040	4,040	4,040	**20,200**
Total	**24,240**	**24,240**	**24,240**	**24,240**	**24,240**	**121,200**

Table 1: Example lengths for 3% maintenance of Example network.

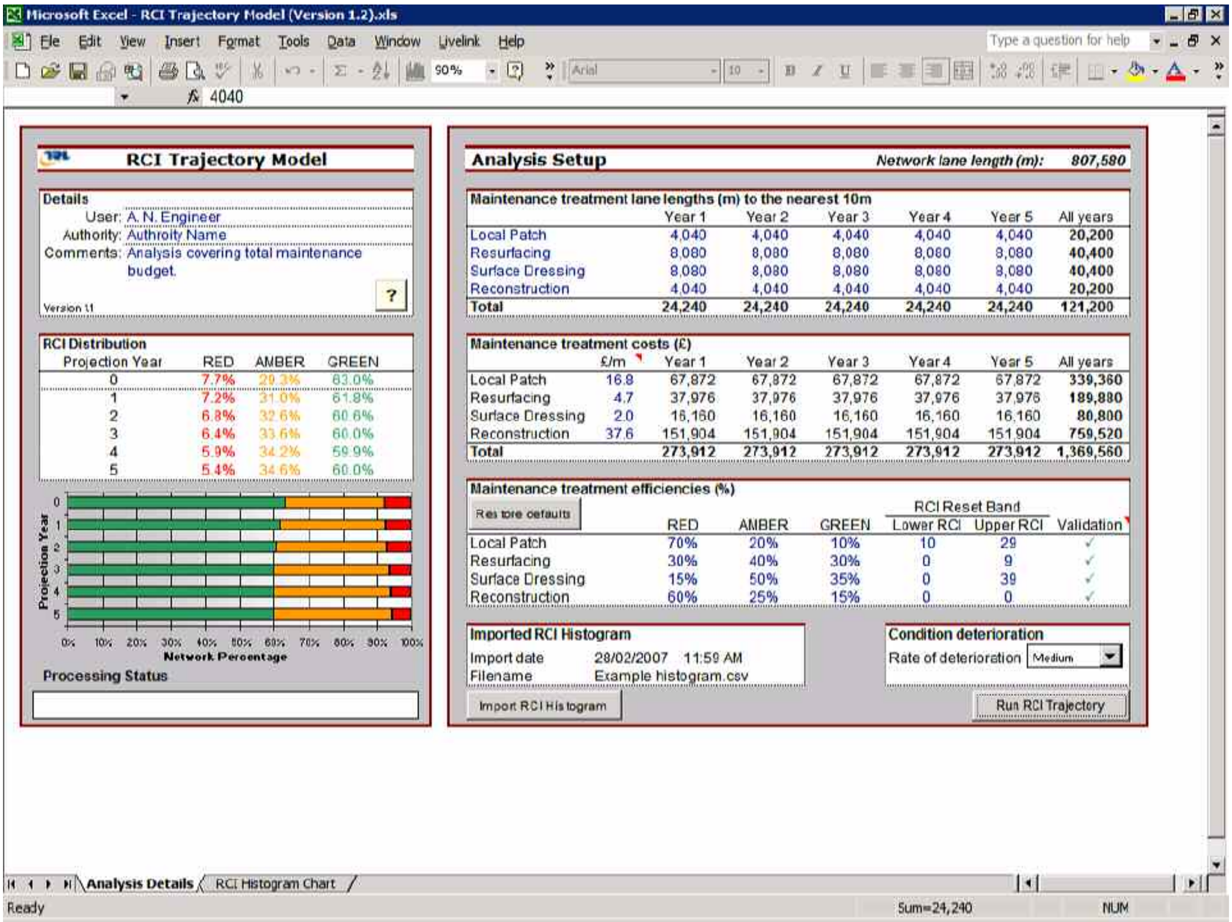


Figure 7: Result of 3% Maintenance on Example Network.

The percentage of the network that must be maintained obviously depends on the deterioration rate, the maintenance lengths and the maintenance efficiencies. These can all be changed by the user in order to produce a more tailor made projection for their network.

Note on use of model output:

The model is not designed to produce a definitive answer regarding what **will** happen to the condition of a given network – merely to give some indication of what **may** happen given certain assumptions about the average rate of deterioration of a piece of road, and the effect of maintenance on that piece of road.

The model is designed to operate at a network level, and the results will not be valid if applied to any particular road or scheme. The results will however give a (hopefully) useful indicator of what will happen to the condition of a network given various levels of investment and following different maintenance strategies.

The default values for the maintenance efficiencies, costs and reset values are provided purely as a start point for your own investigations. All networks are slightly different, and you, as the engineers dealing with your network on a daily basis, are in the optimum position to determine and set the most appropriate values to produce the best predictions of how your network condition will evolve over time.