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**PPR494**

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**Transport Research Laboratory**

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# Bend treatments on the A377 between Cowley and Bishops Tawton: final report

**by Shaun Helman, Janet Kennedy, Andrew Gallagher (TRL)**

**Prepared for: Project Record:** **RSUT/RSAFENG/4839**

**Bend treatment proposals on the A377 in Devon**

**Client:** **Devon County Council,**

**(Peter Gimber)**



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# Contents

# Executive summary

Devon County Council contracted TRL to carry out a number of activities related to the treatment of bends on the A377 between Cowley Bridge (Exeter) and North Tawton. These activities were:

1. Using behavioural data from an instrumented vehicle to assess the validity of using geometric data from SCANNER road maintenance survey vehicles (along with collision data) to assign risk scores to bends on the route.
2. Using a questionnaire study to assess how drivers perceive a signing and marking hierarchy developed to treat bends on the route.
3. Giving advice on how to proceed with further monitoring of *in situ* treatments.
4. Giving broader advice on the approach being taken, including opportunities to develop the use of SCANNER data and behavioural data in the future in other authorities across the UK.

## Background

The A377 is an evolved route; a route safety approach to treatment is preferred, and previous survey work on the route has shown that one key problem perceived by motorists is the lack of a consistent approach to signing bends; the severity of bends is not necessarily matched by the signing and marking present.

## Assigning risk to bends, and choosing a treatment hierarchy

Devon County Council wished to explore an approach of using data from SCANNER road maintenance survey vehicles, along with collision data, to assign a 'risk score' to each bend along the route. The basic approach led to tighter bends, and bends on which collisions had occurred during the period 1/10/2004 to 1/10/2009, being assigned higher risk scores. The SCANNER variables adopted were the radius of curvature of the bend and its camber or crossfall (usually the road either retains normal camber round the bend or has superelevation to aid the driver). The actual method was as follows:

| Factor | Score |
|---|---|
| **First assign a score based on radius of curvature:** | |
| Radius less than 127m | 5 |
| Radius between 127 – 180m | 4 |
| Radius between 181 – 255m | 3 |
| Radius between 256 – 360m | 2 |
| Radius between 361 – 512m | 1 |
| **Then add a score based on cross fall:** | |
| Cross fall less than 2.5% | 1 |
| **Finally add a score for each collision:** | |
| Bend related collision within 100m of relevant bend (Fatal, serious or slight injury) | 1 |

In addition, Devon County Council took guidance from an existing approach to signing and marking bends published by Transport Scotland. The resulting hierarchy consisted of six levels:

1. No treatment
2. As #1 plus a warning sign and edge lines
3. As #2 plus 'SLOW' on road and bar markings

4. As #3 plus chevron
5. As #4 plus high-friction surfacing
6. As #5 plus vehicle activated sign

## Instrumented vehicle study

The objective of the instrumented vehicle study was to undertake a validation of the bend risk scores assigned to bends in the study area by relating these to driver speed choice. It is known that drivers moderate their speed to keep the driving task within a target level of demand (i.e. their 'comfort zone') and therefore it was expected that there would be a negative correlation between risk score and speed driven on the bends.

In the study, 31 local drivers (all regular users of the A377) drove an instrumented vehicle northbound and southbound on a section of the A377 bounded by Newton St. Cyres and Lapford. This included 25 bends, which ranged in risk score from 1 to 9. All drivers drove the route once during the day and once at night. At all times, they were accompanied by an approved driving instructor, who managed the drive in such a way as to help ensure that all drivers were free to choose their own speeds (i.e. that they were not slowed by slow-moving traffic on the bends). Carrying out the drives at quiet times of the day also helped in this regard.

The results showed that overall the bend risk scores did correlate negatively with driver speeds through the bends. This was true even when the effects of existing treatments on the road were taken into account in the analysis.

## Questionnaire study

After their second drive, all participants completed a short questionnaire in which they gave estimated speeds at which they would be travelling when in the road situations depicted. The pictures were of six bend approaches, and were manipulated using Adobe Photoshop software to depict all six levels of the treatment (signing and marking) hierarchy while keeping the actual bends constant. The objective of the study was to see if driver speed estimates were influenced by the different levels of treatment. The results showed that broadly speaking, participants estimated lower speeds the more treatment that was depicted.

## Conclusions

The main conclusions drawn from the study are as follows:

1. The risk scores created by Devon County Council for the bends on the A377 correlated negatively and moderately to strongly with driver speed choice in the instrumented vehicle study. As risk scores went up, driver speed went down. This is what would be expected if the risk scores related to risk or task difficulty, since it is known that drivers vary their speed to control task difficulty.
2. Therefore we can conclude that using SCANNER data to define risk scores for bends, as a broad approach, has validity based on driver speed choice. It represents a pragmatic approach to defining risk scores for bends that can then be fine-tuned if necessary with collision data and other hazards such as junctions.
3. The driver speed data also suggested that drivers varied their speed on bends in response to the existing treatments on the A377. This suggests that Devon County Council's intention to treat the bends on the A377 with a more consistent signing and marking hierarchy is a sensible one that should have some impact on changing driver behaviour on the route.
4. In the questionnaire study, drivers responded to the signing and marking hierarchy with speed estimates in a way that suggested they perceived the hierarchy as expected; as the number of treatments increased, speed estimates

went down, with almost all levels of treatment being significantly or nearly significantly different from all other levels in terms of speed estimates.

5. The analyses reported in this study (of both the behavioural data and the SCANNER data) represent only a fraction of what will be achievable over the longer term; a number of additional analyses are worthy of further research so that the general approach taken by Devon County Council can be assessed for further application outside of the current context in which it has been tested.

## Recommendations

The key recommendations offered from this study are as follows:

1. Devon County Council should proceed with its use of SCANNER data and collision data to assign risk scores to the bends on the A377. However before final risk scores are decided, consideration should be given to adjusting the risk score on the basis of other potential sources of risk such as junctions on the bend.
2. Where there have been multiple collisions on a bend, these should be investigated for any common causal factors.
3. The resulting risk scores should be used as the basis of treatments in the signing and marking hierarchy developed by Devon County Council. It will be necessary to 'group' the risk scores to make six categories. Consideration will need to be given to the different ways in which this might be achieved.
4. The next step in the process should be a controlled 'before and after' evaluation of the new signing and marking hierarchy *in situ* on the A377. The guidelines in Section 5 of this document should be followed in this regard.
5. Further research should be focused on how to expand the broad SCANNER-based approach used by Devon County Council on the A377. A number of other issues present themselves as worthy of further research effort, including the 'smoothing' of SCANNER data by taking moving averages, and the calculation of other safety-relevant variables from SCANNER data such as gradient and estimated forward visibility and 'comfortable handling speed'. Such work should have as its end objective a simple tool that can be used by local authorities to rate bends on their rural road directly from the SCANNER data; the cross-local-authority validity of the algorithms used will need to be validated.
6. We also recommend that Devon, and other local highway authorities, consider gathering 'norms' for speed data on major rural routes that are in need of treatments to address safety concerns. Such survey data need not be over-costly to collect using instructed vehicles, and will provide an invaluable database to be used alongside road geometry and other information in setting priorities for site of high risk on rural roads.

# Abstract

An approach to making bend treatments (signing and marking) consistent on a rural route was evaluated using behavioural data. Risk scores were assigned to bends on the A377 in Devon, on the basis of geometric and cross-fall information from the SCANNER road survey system, and collision data. Bends with tighter radii, low cross-fall values, and more collisions during a defined period, were assigned higher risk scores. A sample of drivers who regularly use the A377 drove a section of the route with 25 bends of varying risk score. The drives were managed by an accompanying driving instructor who attempted to ensure that drivers were free to choose their own speeds throughout. Mean speeds driven through the bends were negatively correlated (moderately to strongly) with risk score, suggesting that the risk scores possessed validity with respect to real driving behaviour (i.e. drivers moderated their speed in a way that suggests they are sensitive to the risk/difficulty of bends, as represented by the risk score). A short questionnaire study elicited speed estimates from drivers in response to picture mock-ups showing different levels of treatments on bends, corresponding to a six-level hierarchy of signing and marking. This showed that drivers lowered their speed estimates as the level of treatment depicted increased. The findings are discussed in relation to the use of the general approach being taken on the A377, and how it might apply to assigning risk, and treatment options, on other rural roads.

# 1 Introduction

## 1.1 General background

Devon is one of four Beacon road safety Local Highway Authorities (LHAs) who were invited in June 2007 by the Department for Transport (DfT) to signify their interest in participating in a Rural Road Safety Demonstration Project (RDP). As a result of this, in January 2008 funding was made available for the implementation of the road safety strategy and programme of specified interventions by the end of March 2010.

Devon County Council was responsible for the planning and delivery of the project known locally as the Country Mile Project. The existing members of the Devon Road Casualty Reduction Partnership, consisting of the Devon and Cornwall Constabulary, Devon and Somerset Fire and Rescue Service, Devon and Cornwall Safety Camera Partnership, South West Ambulance Service and Devon Primary Care Trust, have all contributed to gathering data and proposing shared interventions.

The overall Country Mile Project aims were as follows:

1. To reduce the incidence and severity of road collisions that occur in the project area
2. To achieve improvements to public perceptions and awareness regarding road safety
3. To identify and document the methodologies used to deliver the programme for wider demonstration purposes

Route treatments were adopted as the desired approach, including an aspiration to improve the 'readability' and consistency of signing and marking of the rural road network, especially road curvature on 'A' roads within the overall project area (see Figure 1-1). The overall project area was chosen on the basis of the distribution of injury collisions across the county, taking into account the shared road safety concerns of partnership agencies but with those on the Highways Agency network removed. An area was sought that collected around 1000 casualties over a 5 year period on county roads that were 'rural', and did not include any casualties in settlements of over 5,000 population. Consideration was then given to routes that had a higher than average collision rate, to routes that met the DfT criteria and to an area that had a mixed demographic.

As a result an area bordered by the A361, A377 and A396 was identified as meeting all the criteria.

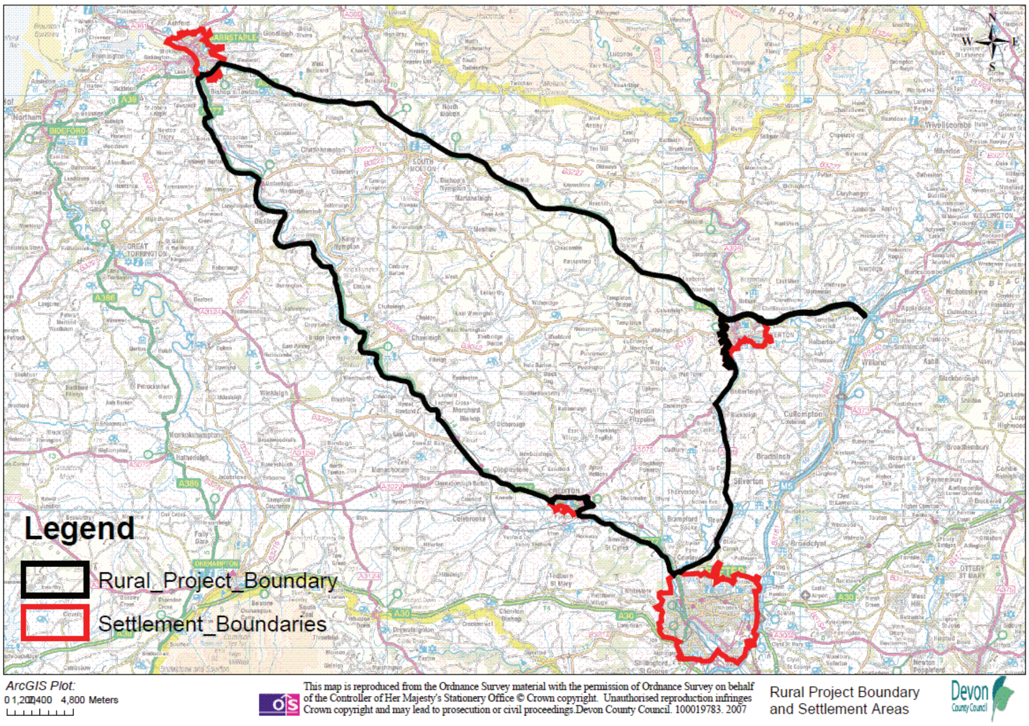


**Figure 1-1: Rural Road Safety Demonstration Project area in Devon**

## 1.2 Background specific to the A377 bend treatment study

The remainder of this report is concerned with one specific part of the wider Country Mile Project, focused on the A377 between Exeter and Barnstaple (the lower 'boundary' of the project area in Figure 1.1). The A377 is an historic route (i.e. it has evolved over time, rather than being 'designed') which makes it very challenging in terms of traditional approaches. . Thus it was decided that a route treatment approach should be taken, using a greater consistency of signing and marking to improve the readability of the road in terms of its complex geometry, in addition to some engineering measures to improve road visibility and road width at some specific sites.

Previous work by Devon County Council has identified that on the A377 there is a key problem with respect to the consistency of signing on bends. Work carried out by Nobel Denton Bomel Limited on behalf of Devon County Council sought to understand how local drivers perceived the A377. Local drivers were deemed the most important group to address on the A377 as the accident statistics held by Devon County Council show that it is local drivers who are most likely to have collisions on the road (as compared to the A361 on which collisions are more likely to involve people who live outside of the immediate area). The recommendations from the Bomel report included making the signing along the A377 more consistent.

Devon County Council assembled a team of engineers and designers to translate the recommendations from the Bomel report into action. In April 2009 a report by Transport Scotland entitled *'Hazard Warning Signs and Markings on Bends on Single Carriageway Trunk Roads'* (Wither, 2006) was brought to the attention of the team. The report describes a process of categorising bends and subsequently signing them according to their category (see Section B.6.1 for further details). The Transport Scotland approach uses design speed as a basis for categorising bends; due to the 'evolved' nature of the A377 it was felt that classification on the basis of design speed alone was not appropriate. However the principle of categorising the 'riskiness' of bends on the basis of objective criteria was supported and therefore an alternative means of categorisation was sought.

Alongside the work to treat the A377, supplementary funding had been obtained to carry out enhancements to a 3km stretch of road between Bickleigh and Tiverton on the A396. Going beyond traditional resurfacing, the scheme used detailed geometric survey data to analyse the alignment and curvature of the road, including the use of 'SCANNER' technology. SCANNER survey machines collect a range of data about the geometry (gradient, cross fall and curvature, etc.) of roads. Typically these data are used to plan maintenance on the network. From the experience of its use on the A396, Devon County Council decided to use SCANNER curvature and cross fall data as a means of categorising bends on the A377. It is well known that collision risk is increased on bends (see e.g. Barker *et al*, 1998, Charlton and de Pont, 2007) and that in general increasing curvature is associated with increased collision risk (see e.g. Charlton and de Pont, 2007). Therefore the use of SCANNER data represents an opportunity to use data already collected by UK councils to categorise the 'riskiness' of a bend without the need for extensive on-site surveys by road safety engineers.

Within Devon County Council's transport laboratory at Littlemoor House, Sowton, Exeter, SCANNER data are recorded and interpreted and as a result of analysis of the information available the team agreed that research should take place into assessing its use to categorise bends. The remainder of this report describes this research:

- Section 2 describes in more detail how Devon County Council approached the issue of assigning risk scores to bends on the A377 by using SCANNER data (and collision data). It also describes the signing and marking hierarchy chosen by Devon County Council for treatment of these bends on the A377.

- Section 3 describes a study (using an instrumented car) that sought to assess the validity of the bend risk scores by comparing them with driving speeds from a sample of local drivers on a section of the A377.

- Section 4 describes a small questionnaire-based study that sought to assess how local drivers perceived this signing and marking hierarchy.

- Section 5 discusses a longer-term monitoring and evaluation plan to assess the effectiveness of the signing and marking hierarchy *in situ*.

- Section 6 discusses potential next steps in terms of additional analyses that could be run using SCANNER data to derive other safety-critical variables (such as forward visibility) from rural roads such as the A377.

- Section 7 presents the key conclusions from the study, and makes recommendations regarding how Devon County Council should proceed in their treatment of the bends on the A377.

- Appendix A describes the process by which the SCANNER data were used by the project team to both check the general approach taken by Devon County Council, and to consider further development of the technique (see Appendix E).

- Appendix B describes in more detail some of the previous work on bend risk and signing/marking in the literature.

- Appendix C offers more detail on the instrumented vehicle study reported in Section 3.

- Appendix D offers more detail on the questionnaire study reported in Section 4.

- Appendix E describes in more detail some of the potential 'next steps' for using SCANNER data identified in Section 6.

# 2 Using SCANNER data to assign risk scores to bends on the A377 and devising a treatment hierarchy

In this section, we briefly describe Devon County Council's approach to using SCANNER data to assign risk scores to bends. We also describe the signing and marking hierarchy devised by Devon County Council. We then discuss the appropriateness of each. A more detailed consideration of the issues raised in this section, along with a short review of some previous approaches, can be found in Appendix B.

## 2.1 SCANNER

The SCANNER (Surface Condition Assessment for the National Network of Roads) survey is a nationally specified survey carried out on all local authority classified roads in England, Scotland and Wales. The current specification (Department for Transport, 2009a) is published on the Pavement Condition Information System (PCIS) website at:

http://www.pcis.org.uk/index.php?p=6/8/0/list,0,58

The survey vehicles accredited to the specification measure a number of parameters along the road and report characteristic values at intervals (nominally every 10m). These include measurements of the vehicle position in three dimensions using GPS and three geometric parameters, radius of curvature, gradient and cross fall.

Local highway authorities in England are currently required to carry out a SCANNER accredited survey covering a minimum of half the length of their A roads each year, and to report their condition using a standardised Road Condition Indicator based on surveys covering the full length of the road (i.e. using data from the most recent surveys, normally collected within the previous 24 months). (Guidance for reporting NI 168 and NI 169 in 2010, Department for Transport, 2009b):

http://www.dft.gov.uk/pgr/roads/network/local/servicelevels/

## 2.2 Devon County Council's approach

Devon County Council has initially assigned six categories of bend signage for bends of increasing risk, after reviewing the approach taken by Transport Scotland (Wither, 2006).

Category 1 – No signing

Category 2 – Warning sign and edge lines

Category 3 – As C2 plus Slow marking and bar markings

Category 4 – As C3 plus chevrons signs

Category 5 – As C4 plus High friction surface

Category 6 – As C5 plus VAS (vehicle activated sign)

In order to decide which bends require which treatment levels however, a method of deciding on bend risk scores was needed. After considerable discussion within the authority, Devon County Council agreed that each bend would be allocated a score in relation to the following variables:

1. Bend curvature data obtained from SCANNER
2. Cross fall data obtained from SCANNER
3. Bend related collision data obtained from STATS19

Bends of 512m radius or less outside of all existing 30 and 40mph speed limit areas between Cowley Bridge and Bishops Tawton were assessed. Usually the road either retains normal camber round the bend or has superelevation to aid the driver.

Table 2-1 shows the way in which this score is built up from these three sources of data.

**Table 2-1: Risk scores assigned to bend on the basis of radius, cross fall, and collision history**

| Factor | Score |
|---|---|
| **First assign a score based on radius of curvature:** | |
| Radius less than 127m | 5 |
| Radius between 127 – 180m | 4 |
| Radius between 181 – 255m | 3 |
| Radius between 256 – 360m | 2 |
| Radius between 361 – 512m | 1 |
| **Then add a score based on cross fall:** | |
| Cross fall less than 2.5% | 1 |
| **Finally add a score for each collision:** | |
| Bend related collision within 100m of relevant bend (Fatal, serious or slight injury) | 1 |

### *2.2.1 Appropriateness of the bend risk score process*

Figure 2-1 shows the frequency of different risk scores that resulted from this method on the A377, when it was applied to the 86 bends on the A377 between Cowley and Bishop's Tawton which have a speed limit of 60mph and a radius of curvature less than 512m. It can be seen that a number of bends scored higher than 6 and only six signing and marking schemes are proposed. However, it is clear that there would be no point in devising a scheme with, say, 12 different categories.

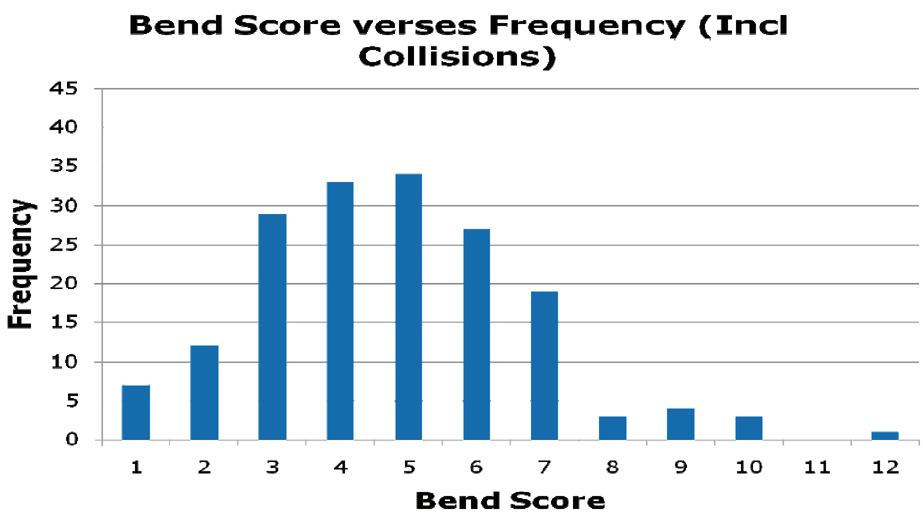


**Figure 2-1: Frequency of different bend scores on A377 using method illustrated in Table 2-1.**

There are a number of issues that need to be considered before final implementation of the Devon County Council approach:

1. Devon has also used the cross fall to assign an additional factor to rating the bend. The approach proposed by Transport Scotland does not explicitly include the cross fall which would be controlled by the design speed approach. It is not immediately apparent how Devon has estimated this factor, or why only a camber of less than 2.5% is given a score for risk. By implication, a comparatively flat camber is regarded as being more risky than a bend with normal camber (or with

super-elevation). The methodology used by Devon is not transparent in this regard, and it would be useful to make it so in further development of the approach.

2. It is not clear why a bend-related collision should have the same score as a change in curvature or in cross fall. There is also a subjective judgement about what is a "bend related" collision and what is not.

3. Another issue relating to collisions is that all bends which have two or more collisions within the period should be investigated individually for common collision factors, for example more than one collision at night or involving a motorcyclist, so that site-specific measures can be considered in addition to the signing and marking proposed for bends in the category concerned. This is particularly important for bends in the highest risk score category, where such measures might be either an addition or an alternative to a VAS, depending on the collision pattern.

4. It is not clear how the scores represented in Figure 2-1 will be collapsed into the six levels of the signing and marking hierarchy. For example, the lowest five categories of risk score could be assigned to levels 1 to 5 of the hierarchy, with all other risk scores falling into level 6. This approach will not result in categories of equal size on this road.

5. No account has been taken of other factors that may be important for the A377, such as forward visibility. This issue is developed further in Section 6.

Despite these issues, in the absence of an established way of categorising bend risk score on evolved roads such as the A377, the approach of using curvature and cross-fall data from SCANNER seems entirely sensible; it is comparatively simple, has the advantages of being transparent and consistent along the length of the road, and bend severity is linked to the 'design speed' approach adopted by Transport Scotland.

### *2.2.2 Appropriateness of signing and marking scheme*

The signing and marking scheme devised by Devon County Council appears sensible. Assuming that it is applied to the bends on the A377 in a way that relates clearly to the risk scores, then it should address the lack of 'consistent' communication of risk that motivated the treatment of bends on the A377 in the first place. One issue that needs to be considered is whether or not the categories of the hierarchy can be distinguished clearly by drivers. In Section 4 we test driver responses to the signing and marking hierarchy using a short questionnaire.

It should be noted that categories 4 and 5 of the hierarchy can only be distinguished by the driver if coloured anti-skid surfacing is used. There is anecdotal evidence that visible skid-resistant surfacing makes some drivers speed up, although it should also increase awareness of the bend.

# 3 Validation of bend risk ratings using behavioural data from an instrumented vehicle

In this section we describe the main empirical activity in the study, in which regular users of the A377 were invited to drive a section of the route in an instrumented vehicle. The purpose of using an instrumented vehicle was to capture naturalistic driving information from the A377 itself, so that the bend risk scores could be understood within the context of behavioural data from regular users of the road. More detail about the instrumented drives, especially regarding the method and analysis, can be found in Appendix C.

## 3.1 Introduction

The key purpose of this part of the study was to validate the approach taken by Devon County Council in using SCANNER data to assign risk scores to bends, in terms of assessing how the risk scores relate to behavioural data gathered from the road itself.

There is a key theoretical foundation on which the approach taken to validation in the study rests. This is that driving is a self-paced task; drivers are known to be sensitive to the ongoing demands of the driving task, and are known to manage the demands of the task by varying their speed (e.g. Fuller, 2005; Fuller et al., 2008). As task demand goes up, drivers respond by reducing their speed. Conversely as task demand drops, drivers respond by increasing their speed. Although there are various disagreements in the literature regarding the actual way in which drivers conceptualise task demand[1], we consider that it is uncontroversial to suggest that the basic self-paced nature of the task remains, for most drivers, for most of the time.

This means that we can make at least two predictions regarding the relationship between the risk scores assigned to bends, and the speeds drivers choose when driving around those bends:

1. Firstly we can predict that if the risk score is valid in terms of how drivers perceive bends, then it should be correlated negatively with speed; as risk score goes up speeds chosen by drivers should go down, as drivers should be sensitive to the extra 'task demand' of higher risk bends, and should vary their speed accordingly.
2. Secondly we can predict that there will be occasions when the relationship between risk score and speed breaks down; specifically when there are other features present on or near a bend that communicate 'extra demand' to drivers—features that are not captured explicitly in the risk score derived from SCANNER and collision data—we would again expect drivers to be sensitive to these features and to vary their speeds, not necessarily in line with what would be predicted by the risk scores.

## 3.2 Method

### *3.2.1 Participants*

The 31 drivers who participated in the instrumented drives were recruited from the area local to the stretch of road used, through internal emails at Devon County Council, and through an advert in a local paper. A number of participants were also recruited through snowballing techniques, by asking participants to suggest other people who fulfilled the required sample characteristics. All drivers took part in one night-time and one day-time drive along a section of the A377. An incentive of £70 was provided, split into £20 given

[1] For example, do drivers conceptualise demand as 'difficulty' or 'risk'? Also what kind of risk is important to drivers – actual statistical chance of crashing or a 'feeling' of risk? Fuller et al., 2008 discusses some of these theoretical nuances in detail.

after their first drive and £50 after their second. All drivers completed both drives. The sample was stratified so that it matched the ages and genders (proportionately) of drivers who had been injured in collisions on the A377, outside of settlements, between 1/10/2004 and 1/10/2009. Thus the sample is representative of the kinds of people of the people who are actually having collisions on the A377.

### 3.2.2 Design

A correlational design was used. The risk scores assigned to each bend were compared to the mean overall vehicle speed driven through each bend by the participants. This made it possible to assess the correlations between the two measures. It was predicted that risk score would be correlated negatively with mean speed; that is, mean speeds were expected to be higher on the bends with lower risk scores.

### 3.2.3 Equipment

The instrumented vehicle was a Ford Mondeo, sourced from Devon County Council's own pool of cars. It was fitted with equipment that permitted the measurement of a variety of variables, including vehicle speed (in km/h) sampled at 1Hz, and accelerometer readings in the vertical, longitudinal and lateral planes, sampled ten times per second. The equipment also recorded a video of each drive, and collected GPS data once per second. This made it possible to locate the vehicle on the route driven, and view video of the view available to the driver at that point, as well as being able to identify spot speed at any GPS point along the route.

After the data were collected, all driver datasets for daytime drives were merged into one file, and the same was done for all night time drives. The 'freeware' software packages Grid InQuest and Quantum GIS (version 1.4.0) were then used to manipulate the data and locate the data points on the bends of interest for the study, using free maps from 'Open Street Map'. The data points were located on the bends by comparing the resulting traces to bend maps provided by Devon County Council of the bends within the trial area. Figure 3-1 shows the same bend in the Devon County Council map and the Quantum GIS software (with GPS plots from the daytime drives overlaid). Note that these maps are at a slightly different orientation and scale in the figure. The extents of the bends are shown on the Devon County Council maps and were located 'by eye' on the QGIS plot to permit data point selection for analysis.

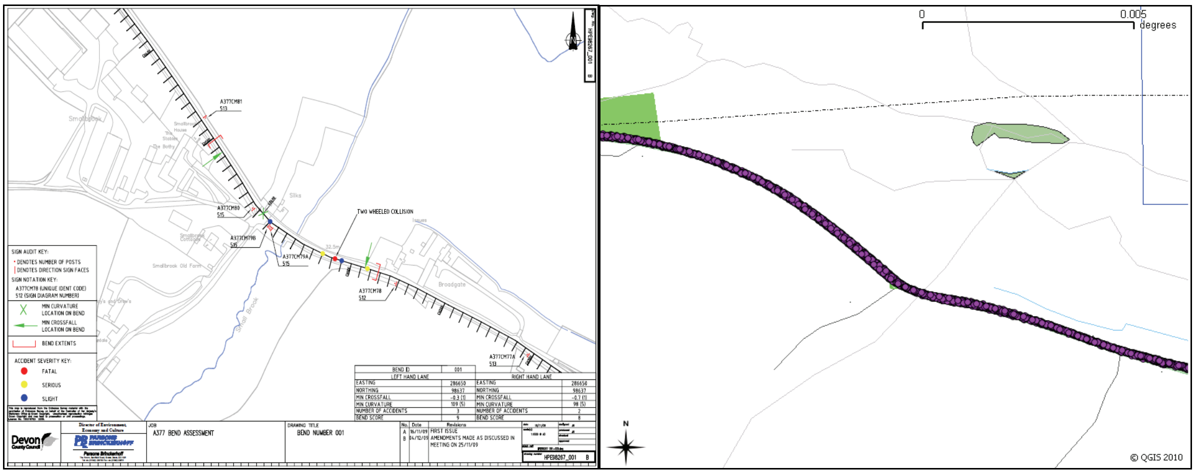


**Figure 3-1: Comparing GPS data in Quantum GIS software overlaid on an 'Open Street Map' map, with maps provided of bends by Devon County Council[2]**

[2] Right hand image © OpenStreetMap contributors, CC-BY-SA, and © QGIS 2010. See http://www.openstreetmap.org/, http://creativecommons.org/licenses/by-sa/2.0/, and http://www.qgis.org/

### 3.2.4 Procedure

A supermarket on the edge of the town of Crediton was used as a base for the instrumented vehicle study. After participants arrived at the store, they were escorted upstairs to the supermarket cafeteria by one researcher to be briefed about the study, and to sign a consent form. The researcher who was an approved driving instructor (ADI) also checked each participant's driving licence. While this was done, the other researcher prepared the instrumented vehicle, which was parked in the supermarket car park.

The ADI then took the participant to the vehicle, stopping in the car park to check the driver's eyesight using the standard driving test procedure of reading a vehicle registration plate at a set distance. The participant then got into the vehicle and was given set instructions by the ADI regarding the drive. The salient parts of these instructions are:

1. Participants were informed that the study was focused on finding out the opinions and perceptions of local drivers, relating to the A377.
2. Participants were informed that the drive was to ensure that when they were interviewed about their opinions and perceptions, they had a recent journey on the road on which to base those opinions and perceptions.
3. Participants were informed that they should drive as they normally would, although they were told that they were responsible for keeping to the posted speed limits. They were also told that for safety reasons, no overtaking was to be permitted, unless instructed to do so by the ADI (e.g. for very slow moving vehicles such as tractors).
4. Participants were not told that the car contained any equipment to record their driving behaviour, although they were told that the camera in the car would record the drive, so that the researchers could refer back to any interesting or salient events mentioned by participants in their post-drive interview.

After the participants indicated that they were happy to proceed, the ADI gave them a short familiarisation drive around the supermarket car park. Then the participants proceeded out onto the A377. The full route is presented in Appendix C. At all times during the drive, the ADI allowed the participant to drive as they saw fit, although he was under instructions to intervene if there was any road safety risk. The ADI did not need to intervene in this manner on any of the trial drives. The one way in which the ADI did intervene when required was to keep the instrumented vehicle away from slow moving traffic if possible, so that the participants were always free to set their own speeds. This was achieved by slowing down on non-bends, and pulling over (when safe to do so) to allow traffic to clear. Participants were told that this was so they experienced the road in free flowing traffic conditions, as that was the main focus of the interview later on. At the end of the drive, participants were interviewed by the other experimenter regarding their experiences of the road, and of the drive. After the second drive, participants were also asked to complete a short questionnaire (see Section 4).

## 3.3 Results

### 3.3.1 Association between Devon County Council risk score and driver speed choice

The vehicle speed data for the 25 bends in the trial drive area were collated from the entire data set as described in Section 3.2.3. The resulting data consisted of spot vehicle speed points for each driver, for each bend, for each direction of travel (north or south) and for both the day and night drives. The number of vehicle speed points varied by driver and bend, since bends were of different lengths and drivers varied in their speed choice, but GPS points were collected every second throughout all of the drives.

However for almost all bends and for almost all drivers, there were multiple speed points. Obvious outliers were removed from the dataset; these included instances where drivers had come to a halt within the confines of a bend (perhaps due to an obstacle on the road) and instances where drivers had chosen extremely low speeds (less than 30km/h) indicating that they were probably being slowed by agricultural traffic. There were very few instances of data being removed from the dataset[3].

A mean speed was calculated for each driver, for each bend, for each direction of travel, separately for the day and night drives. Then, separately for the day and night drives, and for each direction of travel, an average speed was calculated for each bend by taking the mean of all driver speeds on that bend The resulting speed data were then tabulated against the risk scores.

#### *3.3.1.1 Daytime data*

Table 3-1 and Table 3-2 show the data from daytime drives. In each case the bends are sorted according to risk score (highest to lowest). If there were a perfect negative correlation between speed and risk score, we would expect to see speeds increase as risk scores decreased. Broadly speaking this is what we see in the two tables of data from daytime drives, and when the risk score is plotted against the speed data for both northbound and southbound drives (Figure 3-2 and Figure 3-3). This pattern is also reflected in the correlation coefficients between risk scores and speed, as shown in Table 3-3. The correlation for the daytime data is highly statistically significant ($p<0.001$) and can be described as moderate to strong in magnitude. The southbound data correlation is not as high, but is still statistically significant ($p=0.016$) and can be described as moderate in magnitude.

While it is not possible to infer causality from correlational data, the strength of the correlations (especially for the northbound data) is consistent with the interpretation that the risk score captures information about bends that drivers are sensitive to in their choice of speed. If we square the correlation coefficient we are able to estimate the proportion of variance in speed explained by variation in risk score, which in this case is around 40% for northbound data, and around 18% for the southbound data. In short, the speed data from the instrumented drives carried out during the daytime suggest that the risk score derived by Devon County Council from the SCANNER and collision data has some validity in terms of how it relates to driver behaviour. Bends with high risk scores, in general, are negotiated more slowly by drivers, and vice-versa.

[3] Without looking through the video of all drives, it is not possible to know if there were other instances of drivers being slowed by other traffic moving at less ‘extreme’ slow speeds than farm traffic. The feedback from the ADI in charge of managing all the drives is that this occurrence was rare. We are therefore making the assumption that although there will have been some instances of drivers being slightly slowed by other traffic on some bends, these occurrences will have been spread throughout the route, and will not have biased the speed data for any given bend.

**Table 3-1: Day drives, northbound data – risk scores and mean speeds for the 25 bends in the trial drive area**

| Bend | Mean speed (km/h) | Risk score |
|---|---|---|
| 1 | 65.42 | 9 |
| 4 | 71.68 | 7 |
| 12 | 61.92 | 7 |
| 24 | 57.28 | 7 |
| 10 | 69.46 | 6 |
| 11 | 68.54 | 6 |
| 16 | 69.72 | 6 |
| 25 | 65.98 | 6 |
| 27 | 65.95 | 6 |
| 6 | 69.21 | 5 |
| 8 | 74.52 | 5 |
| 26 | 66.92 | 5 |
| 2 | 76.90 | 4 |
| 5 | 70.96 | 4 |
| 7 | 67.35 | 4 |
| 20 | 77.84 | 4 |
| 23 | 74.48 | 4 |
| 18 | 68.85 | 3 |
| 19 | 72.32 | 3 |
| 21 | 79.28 | 3 |
| 13 | 77.91 | 2 |
| 14 | 71.61 | 2 |
| 15 | 74.65 | 2 |
| 17 | 72.48 | 1 |
| 22 | 72.75 | 1 |

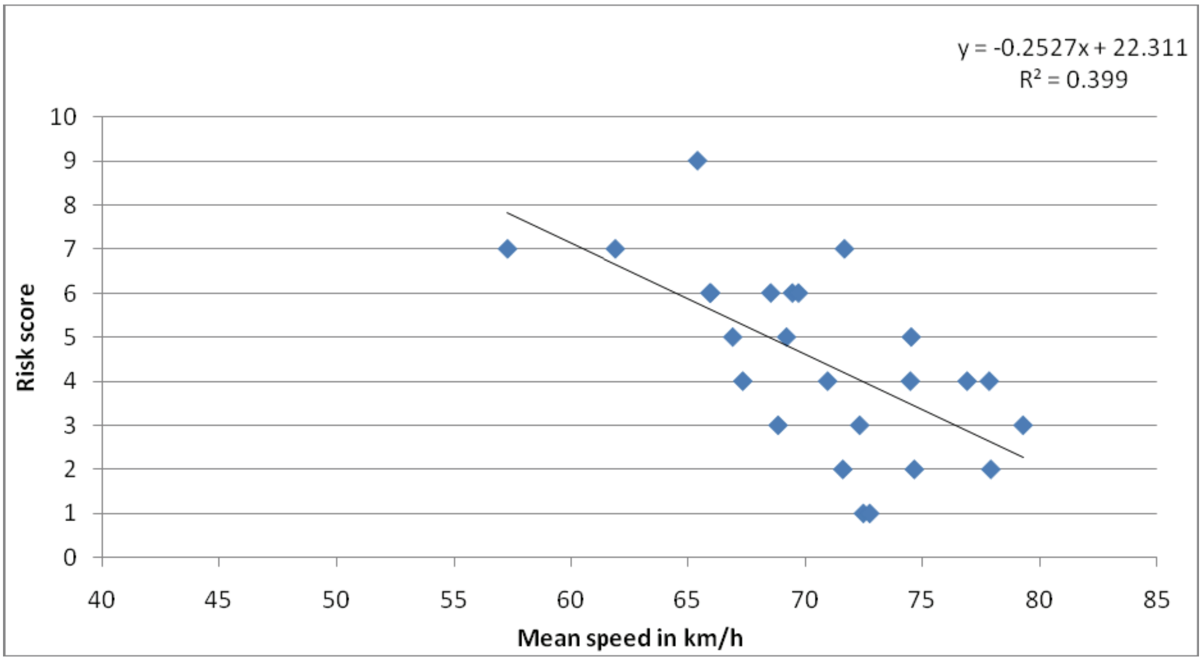


**Figure 3-2: Day drives, northbound data – correlation between risk score and driving speed for the 25 bends in the trial drive area**

Something else that the behavioural data enable is an understanding of where there are bends that do not seem to follow the general pattern of 'higher risk score associated with lower speed'. For example, bend #4 in the northbound and southbound data is among the top three or four bends in terms of risk score, but drivers are clearly choosing a much higher average speed for this bend than would be expected on the basis of this risk score. Similarly, bend #8 in both sets of data seems to have a high speed for its risk score, as does bend #6 in the southbound data (see Table 3-2 below).

These cases are examples of how an approach that combines objective risk information (in this case road geometry and collision history) with behavioural data (in this case speed) can be used to gain an insight into where there may be discrepancies between the risk that is present on a bend (according to the objective measure) but for some reason does not show up in adaptive driver behaviour. The actual reasons for these discrepancies are likely to vary (see Section 3.3.2 for one possible explanation); nonetheless such an approach is powerful as it enables road safety engineers to 'sift' their data to identify potential problem areas, before having to carry out a full safety audit of an entire route.

**Table 3-2: Day drives, southbound data – risk scores and mean speeds for the 25 bends in the trial drive area.**

| Bend | Mean speed | Risk Score |
|---|---|---|
| 1 | 63.96 | 8 |
| 11 | 67.34 | 8 |
| 4 | 72.07 | 7 |
| 16 | 67.45 | 7 |
| 25 | 69.13 | 7 |
| 24 | 57.04 | 6 |
| 6 | 77.43 | 5 |
| 8 | 73.37 | 5 |
| 12 | 59.02 | 5 |
| 27 | 66.31 | 5 |
| 2 | 77.94 | 4 |
| 5 | 78.63 | 4 |
| 10 | 65.48 | 4 |
| 19 | 74.47 | 4 |
| 23 | 77.53 | 4 |
| 26 | 67.98 | 4 |
| 7 | 63.08 | 3 |
| 13 | 74.73 | 3 |
| 14 | 71.07 | 3 |
| 15 | 73.63 | 3 |
| 17 | 67.24 | 3 |
| 18 | 70.65 | 3 |
| 20 | 77.80 | 3 |
| 22 | 75.39 | 3 |
| 21 | 79.45 | 2 |

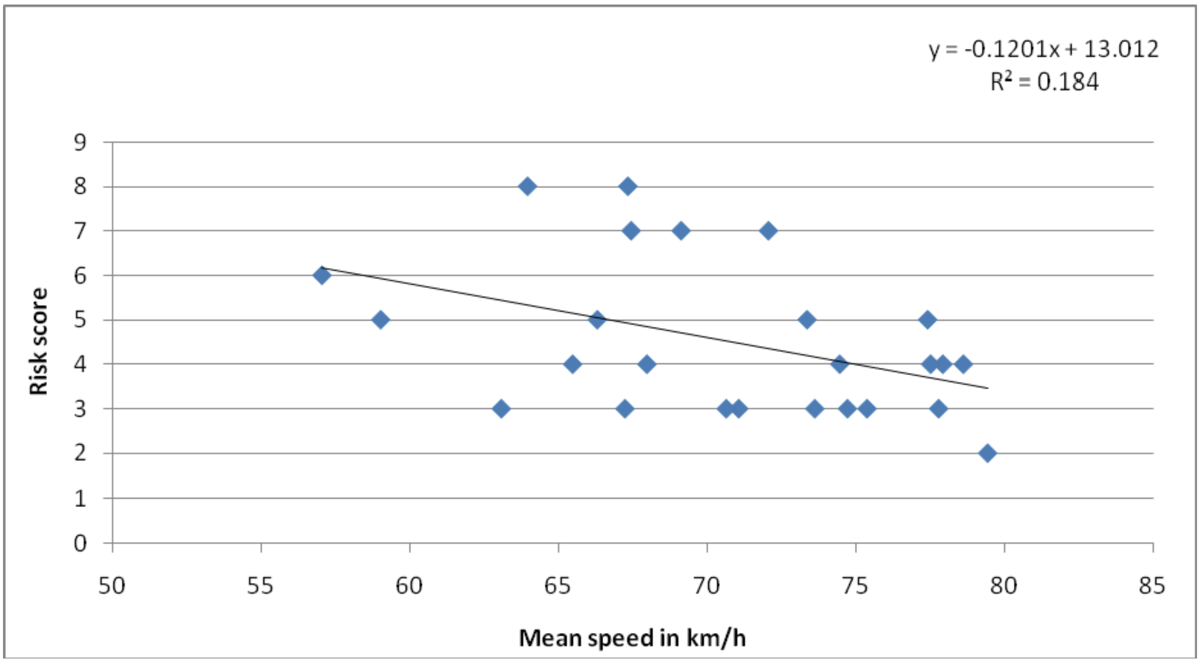


**Figure 3-3: Day drives, southbound data – correlation between risk score and driving speed for the 25 bends in the trial drive area**

**Table 3-3: Pearson's r correlation coefficients (squared values in brackets) between speed and risk score for daytime data**

| | Speed (north) | Speed (south) |
|---|---|---|
| **Risk score** | **-0.632 (0.399)** | **-0.429 (0.184)** |

#### *3.3.1.2 Night data*

Table 3-4 and Table 3-5 show the data from night time drives[4]. Again the bends are sorted according to risk score (highest to lowest). As with the daytime data, in general as risk score goes down, speeds go up, and the correlation coefficients between the risk score and speed for the northbound and southbound data suggest that the risk score is capturing something about bends that drivers also use to manage their speed. Figure 3-4 and Figure 3-5 plot the data, and Table 3-6 shows the coefficients; as with the daytime data, the northbound coefficient is larger in magnitude than the southbound one, but both are statistically significant.

Again it is also possible to identify specific bends on which speeds are higher than might be expected (e.g. bend #s 4, 6, and 8 in both directions).

[4] It can be seen that average speeds were slightly higher at night than during the day. Although all drives were generally managed by the ADI to permit free-choice of speeds by the drivers in the instrumented vehicle, it seems likely that there was still some influence of other traffic on overall speeds driven, and that night time speeds were higher due to their being a lower volume of traffic than during the daytime drives. Since the key question was related to the relative speeds chosen at different bends, rather than absolute speeds, the slightly higher traffic volumes during the daytime drives are not considered problematic.

**Table 3-4: Night drives, northbound data – risk scores and mean speeds for the 25 bends in the trial drive area**

| Bend | Mean speed | Risk Score |
|---|---|---|
| 1 | 61.88 | 9 |
| 4 | 71.50 | 7 |
| 12 | 57.72 | 7 |
| 24 | 54.03 | 7 |
| 10 | 68.13 | 6 |
| 11 | 69.04 | 6 |
| 16 | 69.55 | 6 |
| 25 | 69.57 | 6 |
| 27 | 64.10 | 6 |
| 6 | 77.57 | 5 |
| 8 | 72.15 | 5 |
| 26 | 64.87 | 5 |
| 2 | 77.61 | 4 |
| 5 | 77.59 | 4 |
| 7 | 63.53 | 4 |
| 20 | 74.80 | 4 |
| 23 | 73.86 | 4 |
| 18 | 68.41 | 3 |
| 19 | 72.49 | 3 |
| 21 | 75.61 | 3 |
| 13 | 76.58 | 2 |
| 14 | 72.72 | 2 |
| 15 | 74.63 | 2 |
| 17 | 70.50 | 1 |
| 22 | 73.27 | 1 |

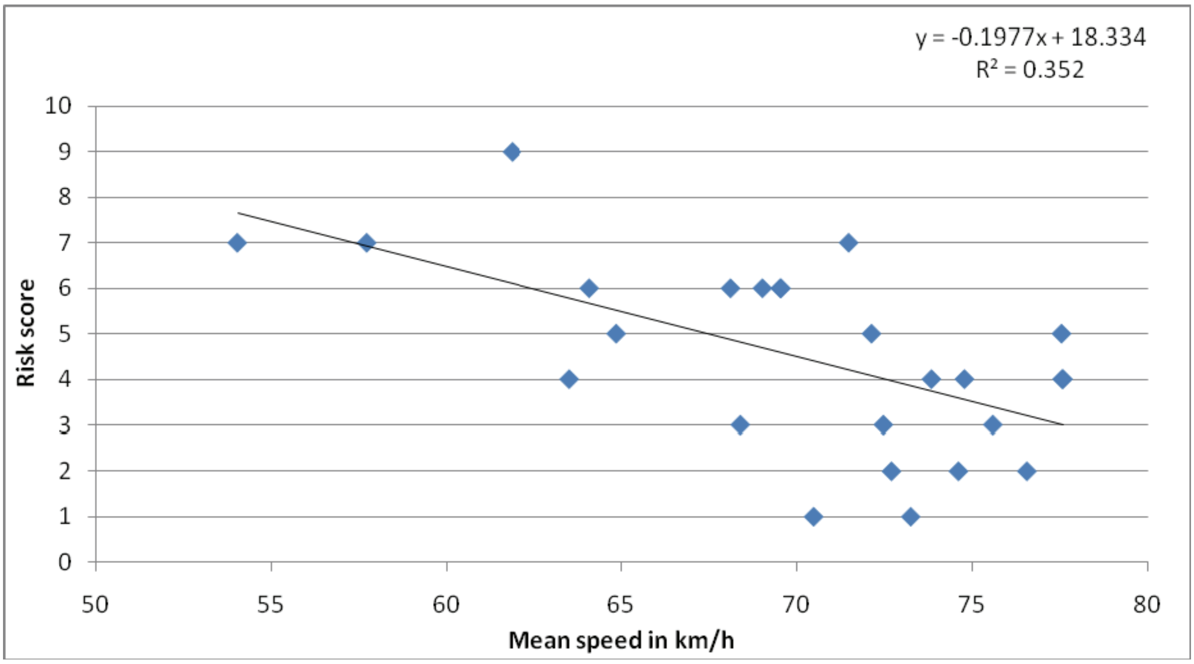


**Figure 3-4: Night drives, northbound data – correlation between risk score and driving speed for the 25 bends in the trial drive area**

**Table 3-5: Night drives, southbound data – risk scores and mean speeds for the 25 bends in the trial drive area**

| Bend | Mean speed | Risk Score |
|---|---|---|
| 1 | 64.30 | 8 |
| 11 | 66.79 | 8 |
| 4 | 71.17 | 7 |
| 16 | 68.30 | 7 |
| 25 | 67.56 | 7 |
| 24 | 55.86 | 6 |
| 6 | 71.32 | 5 |
| 8 | 72.97 | 5 |
| 12 | 60.10 | 5 |
| 27 | 68.36 | 5 |
| 2 | 79.13 | 4 |
| 5 | 73.06 | 4 |
| 10 | 69.73 | 4 |
| 19 | 71.78 | 4 |
| 23 | 74.76 | 4 |
| 26 | 67.78 | 4 |
| 7 | 66.55 | 3 |
| 13 | 76.14 | 3 |
| 14 | 69.79 | 3 |
| 15 | 72.97 | 3 |
| 17 | 72.52 | 3 |
| 18 | 68.51 | 3 |
| 20 | 73.79 | 3 |
| 22 | 68.65 | 3 |
| 21 | 74.38 | 2 |

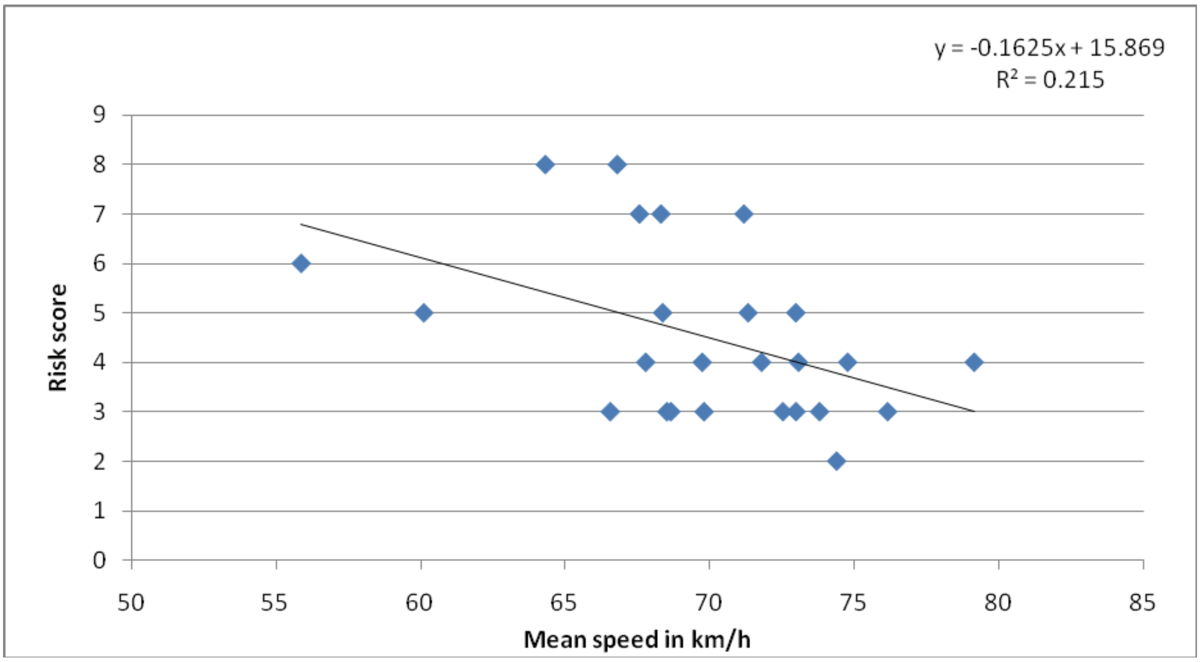


**Figure 3-5: Night drives, southbound data – correlation between risk score and driving speed for the 25 bends in the trial drive area**

**Table 3-6: Pearson's r correlation coefficients (squared values in brackets) between speed and risk score for night time data**

| | Speed (north) | Speed (south) |
|---|---|---|
| **Risk score** | **-0.593 (0.352)** | **-0.464 (0.215)** |

#### *3.3.1.3 Summary of Devon County Council risk score analysis*

Overall the data from the daytime and night time drives in the instrumented vehicle lend some validity to the general approach being taken by Devon County Council in using SCANNER and collision data to assign risk scores to bends on the A377.

The risk score correlated well with the speed data in both daytime and night time conditions. For northbound data the correlation was moderate to strong in magnitude, and for southbound data it was moderate. In all cases the correlation was statistically significant.

There are a number of issues with the analyses done so far however. Firstly, it is not clear why some bends seem to elicit higher speeds than might be predicted from their risk scores; it is likely that there are other sources of information that lead to drivers adjusting their speeds, and that this information is not currently captured by the risk score. Secondly, the current analysis does not control for the potential impact of existing treatments (signing and marking) on speeds. Both of these general points need to be addressed if we are to have a more robust understanding of driver speed choice on bends in the data sets.

In Section 3.3.2 we address these issues by looking at the correlations between speed and different versions of risk scores that taken into account these limitations.

### *3.3.2 Different approaches to the risk score: the influence of collisions and existing signage*

The findings reported in Section 3.3.1 are clearly encouraging; they suggest that the risk scores assigned to bends on the basis of the SCANNER data (and collision data) relate well to driver speed choice through the bends, as measured in the instrumented vehicle. In terms of a practical way to assign risk scores to bends, without having to carry out extensive on-site audits from the outset, the approach chosen by Devon County Council seems workable, and valid.

Another prediction made in Section 3.1 however was that there would be other features on bends on the A377 that might also influence speed choice, and that if these features were not captured by the Devon County Council risk score, then they may lead to a breakdown in the relationship between the risk score and speed. Therefore we should expect to be able to improve the 'fit' between the risk score and speed data, if we account for these other potentially speed-influencing factors.

We have identified three features that we think are relevant in this regard:

1. Previous collision data are currently included in the bend risk score. While this makes sense from a practical perspective, it may not make sense when trying to understand the link between risk score and speed choice. The reason for this is that unlike curvature information, collision data are not readily available to be perceived by drivers as they drive through the route. Drivers would not be expected to be able to vary their speed according to data they cannot perceive. Therefore removing collision data from the risk score might improve the fit with speed data.

2. Junctions on or around bends should be a source of task demand to drivers, since drivers need to monitor these junctions in order to be sure that no traffic is likely

to pull out in front of their vehicle. Therefore we might expect that adjusting the risk score for the presence of junctions (within the bend extents) would improve the fit with the speed data.

3. Existing treatments (signs, markings etc.) will also potentially add to task demand (or at least communicate risk) and if we adjust the risk score to take account of this again we might expect to improve the fit with speed data.

In order to assess the impact of these variables, we created another three risk scores (based on the original Devon County Council one) and then examined how this influenced the correlation with speed. The three additional risk scores were:

1. **Original minus collisions:** the Devon County Council Risk score, but with the 'previous collisions' element removed. For example if a bend had an original score of 6, and this included 2 collisions, the revised score would be 4.
2. **Original minus collisions plus junctions:** as (1), but with the number of junctions within the bend extents added. For example, if our bend that scored 4 had a junction within its extent, then it would now score 5.
3. **Original minus collisions plus junctions plus treatments:** as (2), but with the number of different treatments present on or around the bend[5]. Figure 3-6 illustrates some of the different treatments coded. The complete list is as follows: bend warning sign, edge lines, 'Slow' in road, chevrons, high friction surfacing, VMS, junction warning sign, skid warning sign, blind summit, other 'slow down' signs. Each of these treatments being present (one or more of a given treatment) added one to the risk score. For example, our bend that scores 7 on risk score #2, if it had a bend warning sign, two skid warning signs, and a chevron sign, would score 10 (7+1+1+1)[6].

Each risk score was correlated with speed data in the same way as described in Section 3.3.1. Table 3-7 shows these correlation coefficients. A number of findings are apparent.

Firstly in all but one case the corresponding correlations are stronger in magnitude in the day time data, although this difference is very small. This makes sense, since visual information captured in the different risk scores (e.g. curvature, presence of treatments) will be less visible at night.

Secondly in both daytime and night time southbound data, removing the part of the risk score that is made up of collision data increases the magnitude of the correlation between the risk score and the speeds. This is what we would expect, given that drivers cannot 'perceive' previous collisions, and therefore it is not likely that they would influence driving speed.

Thirdly, in all cases, adding a junction component to the risk score does not make any real difference to the magnitude of the correlations. This may be due to the fact that the variability in the junction component of the risk score is limited (typically junctions only had zero or one junction on or near them) and therefore the sensitivity of the statistical test to the presence of junction information is low. Alternatively, it might suggest that drivers do not really pay any attention to the presence of junctions when choosing their speed around bends.

The final key finding is that including existing treatments within the risk score increases the fit between the risk score and speed, especially for the southbound data. This

[5] The lead author made a subjective decision as to whether a particular treatment was associated with the bend or not.

[6] It should be noted that the decision to assign a score of '1' to each of these treatments is entirely arbitrary; in using the simplest possible approach (i.e. not weighting any specific treatments more than any others) we aim to assess what impact the 'total number of different treatments' has on the relationship between risk score and speed. Future refinements would need to examine whether different treatments have different effects, on a given road.

suggests that drivers were varying their speed in response to existing treatments, although causality cannot be proven from correlational data.


**Figure 3-6: Examples of some of the different existing treatments associated with bends on the A377. These images are captured from the video footage of the drives.**

**Table 3-7: Correlations between additional risk scores and speed from the instrumented drives by day and night and by direction (Squared values in brackets).**

| | Daytime data | | Night time data | |
|---|---|---|---|---|
| | **Northbound** | **Southbound** | **Northbound** | **Southbound** |
| **Original risk score** | -0.632 (0.399) | -0.429 (0.184) | -0.593 (0.352) | -0.464 (0.215) |
| **Original risk score minus accidents** | -0.652 (0.425) | -0.618 (0.382) | -0.599 (0.359) | -0.591 (0.349) |
| **Original risk score minus accidents plus junctions** | -0.659 (0.434) | -0.592 (0.350) | -0.600 (0.360) | -0.558 (0.311) |
| **Original risk score minus accidents plus junctions plus existing treatments** | -0.683 (0.466) | -0.778 (0.605) | -0.638 (0.407) | -0.711 (0.506) |

The fact that existing treatments are related to driver speed is worthy of further investigation within the context of validating the risk score approach being used by Devon County Council. It is actually possible that the correlation between the Devon County Council risk score and speeds is entirely due to the fact that risky bends (i.e. those with more curvature, and more collisions) may have attracted more warning signs and other treatments over the evolution of the A377. In fact, there is a positive correlation between the Devon County Council risk score and the number of existing treatments (Pearson's r=0.633 and 0.677 for northbound and southbound route respectively).

To rule out the possibility that the correlations reported in Section 3.3.1 are due to this confounding of risk score with existing treatments, partial correlation analyses were carried out. These analyses test whether there is a correlation between two variables (in this case the original Devon County Council risk score and speeds from the instrumented vehicle drives) when the effects of a third, related variable (in this case the existing treatments on the bends) is removed. For the northbound data, day and night, these analyses confirmed that the correlation between risk score and speed held even when the effect of treatments was removed (r=-0.458 and -0.361 for day and night data respectively, $p<0.05$ in both cases) . For southbound data this was not the case when using the original risk score, for either the daytime or night time data. However when the risk score without the collision data included was used, the correlation with speed remained even when the effect of existing treatments had been removed (r=-0.516 and -0.472 for daytime and night time data respectively, $p<0.05$ in both cases). It is also worth noting that the effects of existing treatments may explain why some bends seem to be driven at higher speeds than their risk scores would predict. This can be illustrated by looking at the data in Table 3-1 again, but this time sorting the bends by the risk score that includes the existing treatments.

Table 3-8 shows this, just for the daytime northbound data. As can be seen bend 4, which on the basic risk score was rated as the joint second riskiest bend, on the risk score that includes existing treatments would only be expected to be the joint seventh riskiest bend. When all of the information available to drivers to help them decide their speed is included in the risk score, the slightly higher speed chosen at this bend (than would be predicted on the basis of the road geometry) makes sense; there is no existing treatment at this bend and therefore people choose higher speeds. This, in essence, is simply more evidence from the A377 itself that a more consistent hierarchy of treatments on bends is needed, if appropriate speeds are to be attained.

**Table 3-8: Day drives, northbound data – risk scores (including existing treatments) and mean speeds for the 25 bends in the trial drive area.**

| Bend | Mean speed | DCC risk score minus collisions plus junctions and existing treatments |
|---|---|---|
| 24 | 57.28 | 13 |
| 11 | 68.54 | 13 |
| 12 | 61.92 | 11 |
| 25 | 65.98 | 11 |
| 1 | 65.42 | 10 |
| 16 | 69.72 | 10 |
| 4 | 71.68 | 7 |
| 10 | 69.46 | 7 |
| 8 | 74.52 | 6 |
| 14 | 71.61 | 6 |
| 27 | 65.95 | 5 |
| 26 | 66.92 | 5 |
| 2 | 76.90 | 5 |
| 18 | 68.85 | 5 |
| 19 | 72.32 | 5 |
| 5 | 70.96 | 4 |
| 7 | 67.35 | 4 |
| 20 | 77.84 | 4 |
| 23 | 74.48 | 4 |
| 6 | 69.21 | 3 |
| 21 | 79.28 | 3 |
| 13 | 77.91 | 2 |
| 15 | 74.65 | 2 |
| 17 | 72.48 | 1 |
| 22 | 72.75 | 1 |

## 3.4 Discussion

The data reported in this section from the instrumented drives have shown that the approach being used by Devon County Council in assigning risk scores to bends on the basis of SCANNER and collision data is broadly valid in terms of how these risk scores relate to driver behaviour (speed choice). Broadly speaking, when risk score went up, the speeds drivers chose went down. There were robust correlations between driver speed and risk scores, and when (for the purpose of validation) the risk score was adjusted to exclude previous collisions, this relationship grew in magnitude, especially for the southbound data.

There is also evidence from the instrumented drives that existing treatments had an effect on driving speeds. However when the influence of existing treatments was removed statistically significant correlations still remained between driver speeds and either the original risk score (northbound data), or the modified 'no collisions' risk score (southbound data).

The data reported in this section represent a fraction of the data available from the instrumented vehicle drives. However the relatively simple variables involved map onto well-known features of the self-paced nature of the driving task (i.e. the fact that drivers modify their speed to control task difficulty). They also provide evidence of the validity of using SCANNER data to assign risk scores to bends on this type of road, and of the importance of good treatment of these bends using consistent treatment hierarchy. The hierarchy is the focus of the next section.

# 4 Validation of signing and marking hierarchy using behavioural data from post-drive questionnaire

In order to assess broad responses to the signing and marking hierarchy developed by Devon County Council, a small questionnaire-based study was run after the instrumented car drives. In this section we describe the method and results of this study. For brevity we only report the data from the main dependent variable (estimated normal speed) in this report.

## 4.1 Method

### *4.1.1 Participants*

The 31 drivers who took part in the instrumented vehicle drives served as participants for the questionnaire study.

### *4.1.2 Design*

The dependent variable was the mean 'normal speed' reported by participants in response to the pictures (see Section 4.1.3). This was the speed that participants said they would normally be driving in the driving situation depicted in the picture. The data were analysed using a two-way analysis of variance (ANOVA) using the statistical software package SPSS (v14). There were two independent variables. These were 'treatment level' (1, 2, 3, 4, 5, and 6, referring to the treatment levels in the Devon County Council hierarchy) and 'bend' (a, b, c, d, e, and f, referring to each of the six bend pictures used).

This design enabled us to understand whether participants' speed estimates differed significantly for the different levels of treatment, and also whether this was true for all the bend pictures we had used, or only some.

### *4.1.3 Materials*

A questionnaire was developed that used pictures of bends not local to the A377, that were edited using the Adobe Photoshop software package to create views that corresponded to each treatment level of the Devon County Council hierarchy. Non-local bends were used to help ensure that participants would not be familiar with the bends, and thus that their speed estimates would be guided by an honest appraisal of the bend presented in the picture, rather than any memories of their everyday experience with a familiar bend.

The questionnaire is described in detail in Appendix D. Briefly, the questionnaire consisted of six bends that were each 'mocked up' to correspond to each of the six treatment levels in Devon County Council's hierarchy (i.e. levels 1 to 6). Figure 4-1 shows a single bend in all of the treatment levels. The pictures were not accurate 'real world' depictions of how the bends would look if treated; for example the treatments were 'squeezed' into a shorter depth of view than would be used *in situ*, to allow for standardised viewpoint comparisons of the different levels. This may have led to greater emphasis being placed on surface markings compared to chevrons. However for the current purpose (i.e. establishing broad order of responses to the different levels of the hierarchy) this method was deemed appropriate.

The pictures of 'treated' bends were presented in the questionnaire booklet in a different pseudo-randomised order[7] for each participant. Also included in the pseudo-randomised order were pictures of nine other bends (different ones from the ones used in the

[7] The order was completely randomised using the 'Rand' function in Microsoft Excel, and then the order was changed manually until no single bend was seen sequentially.

Photoshop mock-ups) from the Berkshire area, used to serve as distracters (i.e. to help avoid participants immediately realising that they were seeing the same six bends over and over again with different treatment levels). Participants were asked to give a speed (in mph) that they would drive in the situation depicted, if the picture represented their view of the road ahead, in their usual car.

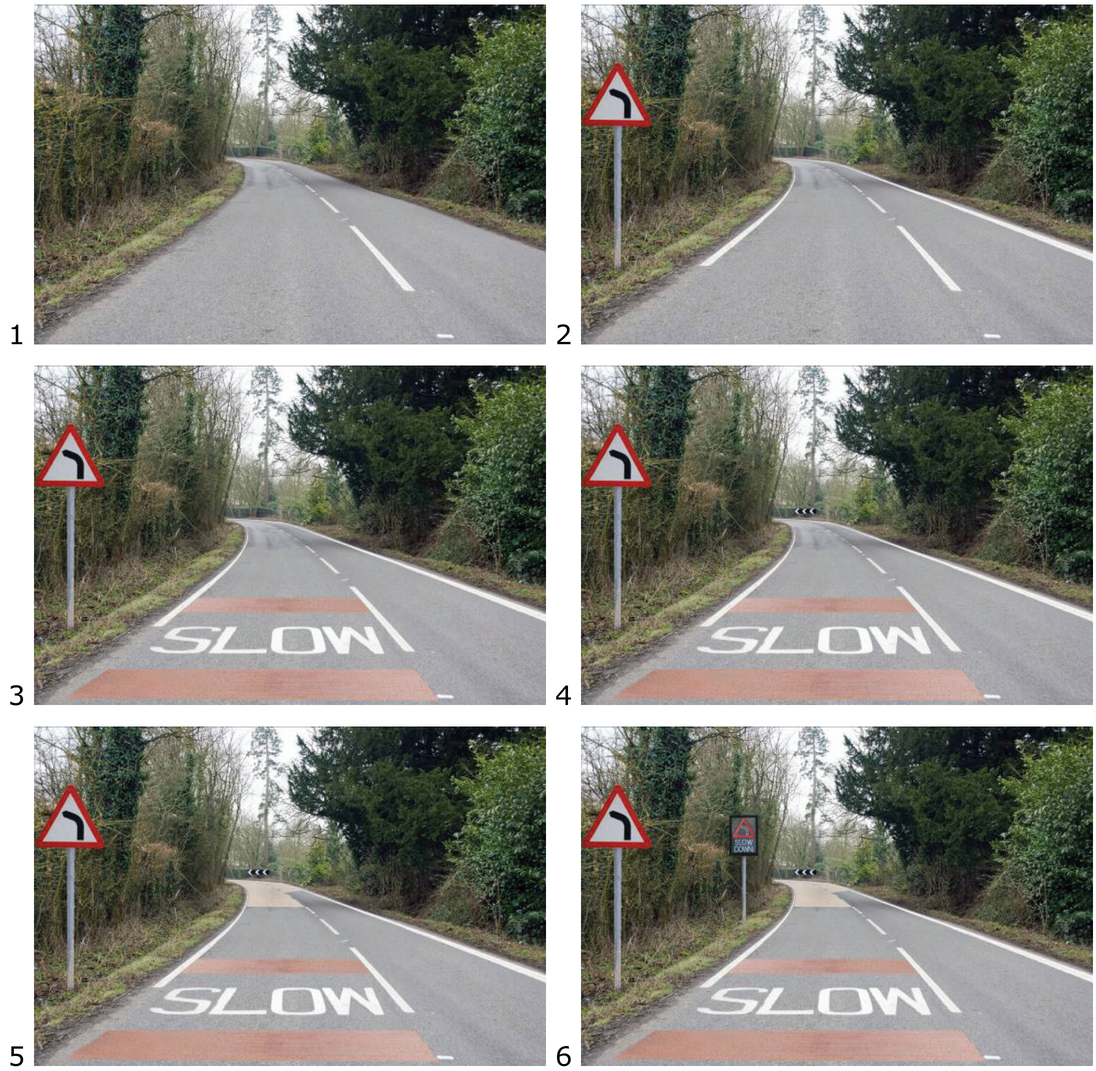


**Figure 4-1: Experimental bend 'a' altered in Adobe Photoshop to correspond to the six different treatment levels (1 to 6) in the Devon County Council Hierarchy**

#### *4.1.4 Procedure*

Each of the people who had taken part in the instrumented vehicle drive was asked after their second drive to complete a short questionnaire. The questionnaire described in detail in Appendix D was given to each participant, and the experimenter worked through the front page (instructions and examples) with them. Participants then completed the questionnaire by themselves. The majority of participants took around ten to twenty minutes to complete the questionnaire.

### 4.2 Results

Analysis showed that mean speed estimates (to the first 'normal speed' question) chosen by participants varied by treatment level. Figure 4-2 shows the mean speeds chosen for each treatment level. The data show that as the treatment level went up (i.e. more signing and marking options were added) participants' mean speed estimates went down. The highest treatment level bend mock-ups elicited 'normal speed' estimates 6.64mph lower than the bend mock-ups with no treatment.

The analysis also showed that the speed estimates differed by treatment level in the same way for each bend used in the mock ups.

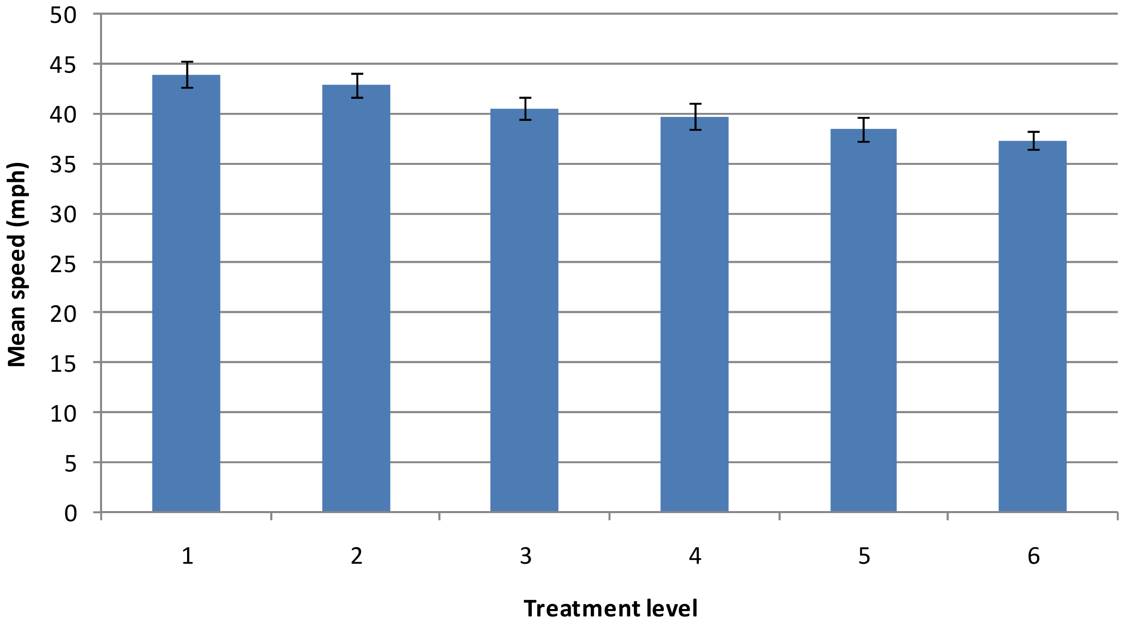


**Figure 4-2: Mean 'normal speed' (mph) chosen by participants in response to pictures with the six different treatment levels (corresponding to the six levels of the Devon County Council signing and marking hierarchy). Error bars are standard error of the mean.**

A further analysis to establish which individual treatments had an impact on speed estimates showed that all bend treatment levels were either significantly different (i.e. $p<0.05$) or marginally significantly different (i.e. $p<0.10$) to all other bend treatment levels, with the exception of levels 3 and 4, which did not differ. It is likely that this was caused by the fact that the visible change between these two levels consisted of a chevron sign being added in the distance on the bend itself. This change was visually small (as can be seen in Figure 4-1) and it is possible that participants did not always notice it. This is a slight methodological weakness in the current study, although not problematic for the main purpose of finding out if drivers view the treatment levels broadly as intended.

## 4.3 Discussion

Overall the data from the questionnaire study show that broadly speaking, the sample of drivers used responded to the different levels of the treatment hierarchy as we would expect if they view the hierarchy as an increasing indicator of risk or task difficulty on the bends in question.

These findings cannot be used to establish the likely speed reductions that would be seen in real-world applications of these treatments. However they can be used to gain an insight into the likely relative impact of the different treatment levels. Combined with the data from the instrumented vehicle drives, these data suggest that the approach being taken by Devon County Council to treating bends on the A377 (more treatment for bends with higher risk scores) is likely to have a reasonably predictable effect on speeds (i.e. more speed reduction for more treatment).

# 5 Next steps - monitoring

The behavioural data collected in this study have shown three things:

1. The broad approach being taken by Devon County Council to assigning risk scores to bends has some validity based on the driver speed data; as risk score increased, the average speed chosen by drivers in the instrumented vehicle decreased, which is what would be expected if we assume that drivers moderate their speed according to the risk or difficulty present in the driving situation.
2. Drivers' speeds in the instrumented vehicle were also associated with the amount of signing and marking already present at the bends.
3. The questionnaire study showed that the hierarchy of signing and marking is perceived by drivers in broadly the way intended (i.e. as the number of treatments increase, drivers speed estimates decrease).

Given these findings, the next step for Devon County Council is to begin treating the bends on the A377 with the signing and marking hierarchy, on the basis of the risk scores (although see Section 7 for recommendations regarding other information that might be considered as part of the risk score. Note also the difficulty in relating the risk score to the hierarchy). It will be crucial that the *in situ* impact of the treatments is also evaluated as part of an ongoing monitoring plan. In this section we discuss several issues that need to be considered when monitoring the impact of the treatments.

## 5.1 Issues to consider

With respect to the monitoring plan for the A377 Country Mile project, the following points need to be considered:

1. The 85$^{th}$ percentile speeds on the approach to and the apex of bends should be measured.

2. Preferably the equipment being used will record individual vehicle speeds rather than 'binned' data (i.e. data that places observed values into defined ranges such as '40 to 50 mph' and '60 to 70' mph), as this will be more flexible when it comes to analysis. However if 'binned' data are collected this should still be useable for the '85$^{th}$ percentile' measure.

3. A week of data (including weekends and day/night) should be collected for the before and after period(s). This will ensure that there are enough data points to draw meaningful comparisons between the periods.

4. Ideally the use of two 'after' periods should be considered. One short term (say within a month of the treatment installation) and one longer term (at least three to six months and preferably a year after).

5. There are two things that need to be considered about the precise placement of equipment:

    a. The placement of the equipment; ideally in addition to the apex of the bend, the point where the bend begins (the 'entry' point when the radius begins) should be chosen as the data collection point, as it is by this point that speed reductions are desirable. Devon County Council has access to the locations of the limits of bends from the work done by Parsons Brinckerhoff. Practical limitations will also play a role of course in defining where the equipment will go.

   b. Whatever is decided for 'a', it is utterly essential that the equipment is put in exactly the same place (for a given bend) for both the 'before' and 'after' period(s).

6. A range of different bend severities should be included in the treatment – preferably at least two from each level of the hierarchy. This will permit an understanding of whether the 'hierarchy' of treatments is associated with an increasing amount of speed reduction. The 'no treatment' category effectively acts as a control condition.

7. With respect to the absolute number of bends included – the more the better. The nature of the evaluation will be such that the treatments are confounded with the bends on which they are used. Also, potential 'migration' effects of the treatments will be different depending on the bends that are treated and those that are monitored, and their relative positions along the route. For example, if a bend is treated with a category six treatment, and this is just before a bend that is not treated at all, then this second bend may 'leach' some of the effects of the previous category six treatments if drivers take a more cautious approach for a time after the bend that is treated. The more bends in the monitoring, the more such confounding effects can be expected to 'even out'.

8. The weather conditions need to be recorded on every day (at least) and preferably at points during the day, at each site. Weather (surface water and fog especially) will have a major impact on speed choice and needs to be controlled in the analysis. In addition, we will need to know when it is dark at each site, on each day.

9. Finally, it will be important when analysing the data to take into account the existing signing and marking at each bend, both during the 'before' and 'after' periods. For example, it might be the case that two bends that are to be treated as 'category six' bends in the after period have different levels of existing signing in the 'before' period then we might expect. On the basis of the speed data from the instrumented vehicle study we might expect different levels of 'before' signing and marking to be associated with different speeds, even on bends that are otherwise identical in terms of their geometry. Thus, the potential change in speed in the 'after' period would be influenced by the existing signing and marking on each bend.

## 5.2 Example 'minimum best-case' monitoring design

Taking into account all of the points in Section 5.1, the recommended 'minimum best-case' design for a monitoring study of the different treatments on the A377 is as follows:

1. At least two bends from each severity level should be included in the monitoring.
2. These bends should all be non-adjacent to each other to avoid possible 'migration' effects.
3. Data collection points should be identified for each bend, in each direction of travel, preferably on the apex of the bend and the approach.
4. Equipment (capable of measuring individual vehicle speeds) should be installed at all bends in the study during a single 'before' period, which should be one-week long, and should be as close as possible in time to when the treatments are to be installed.
5. After treatments have been installed, the same equipment should be installed at all data collection points again a month later, for the first one-week-long 'after' period.

6. The data collection should be repeated at least three to six months later, preferably a year, again at all data collection points.
7. Note should be made throughout the study of weather and lighting conditions at each site, for each day.

## 5.3 Analysis

It is outside of the scope of this report to present a detailed section on the handling and analysis of the data from the before/after monitoring. However in broad terms the analysis should seek to compare any change in the mean and $85^{th}$ percentile speeds at each site with the change in mean and $85^{th}$ percentile speed at the control (i.e. non-treatment) site(s). If the different levels of treatment are successful in lowering mean and $85^{th}$ percentile speeds, then this should show up in the analysis as a statistically significant interaction between the type of site (treatment or non-treatment) and the time at which measurements are taken (before versus after). In other words, there should be a greater change (ideally a drop) in speeds at treatment sites than at the control sites.

It is assumed that there will be data analysts at Devon County Council who have the skills necessary to run the analysis.

# 6 Next steps – using SCANNER data to assign risk scores to bends and road sections

The behavioural data from the instrumented vehicle, reported in Section 3, suggested that the broad approach taken by Devon County Council in using SCANNER data to assign risk scores to bends is one that has some validity. Driver speed choice (a behavioural index of risk as perceived by the driver) was correlated negatively with risk score; as the risk score increased, the average speed chosen through the bend went down. This correlation increased in magnitude when that component of the risk score on each bend made up of collision data (i.e. that component of the risk score on each bend that is not perceptible to drivers as they drive) was removed. In addition, the negative correlation between speed choice and risk score remained (albeit reduced in magnitude) when the effect of existing road signage was removed.

That the broad approach has some real-world validity data to back it up is particularly encouraging given that UK local authorities already have access to SCANNER data; the approach being pioneered by Devon County Council represents an innovative and cost-effective application of these existing maintenance and management data to the road safety domain.

In this section we consider several ways in which we believe that the broad approach to using SCANNER data in this way can be developed further. We also discuss the need for these further developments, within the context of the applicability of the approach to different local authority areas in the UK; the different topographical and geometrical properties of evolved roads in different areas of the UK are likely to require some fine-tuning of the approach.

## 6.1 Curvature measured by SCANNER

As covered in Section 2, the general approach taken to using the SCANNER data variables on curvature and cross-fall as the key inputs into assigning bend risk scores seems technically sound.

One difficulty with analysing SCANNER radius of curvature data is that very large values of radius correspond to almost straight roads, so a very slight deviation in the road alignment, or even a minor correction in the direction of steering, can cause the value to swing from a very large number to a very small number, or vice versa. Whereas small values of radius of curvature represent tight bends and are of particular interest. Therefore it is easier to analyse curvature (the inverse of radius of curvature) which is a very small number on straight roads, and a much larger number at bends.

Because the value is measured on the vehicle driving line, there is some variability from point to point. One way of reducing this variability is to average the value of curvature along the road. It has previously been found with other SCANNER parameters that averages of 3, 5, or 9 readings can be more consistent than single point values. In this case, a moving average of 5 values seems to give a smoother result, enabling better discrimination between places where measurements have been affected by driving line. This can be illustrated by comparing the curvature in the north and southbound directions with the value, averaged over five subsections over about 1 km of the A377 just south of Lapford Cross (Figure 6-1 and Figure 6-2).

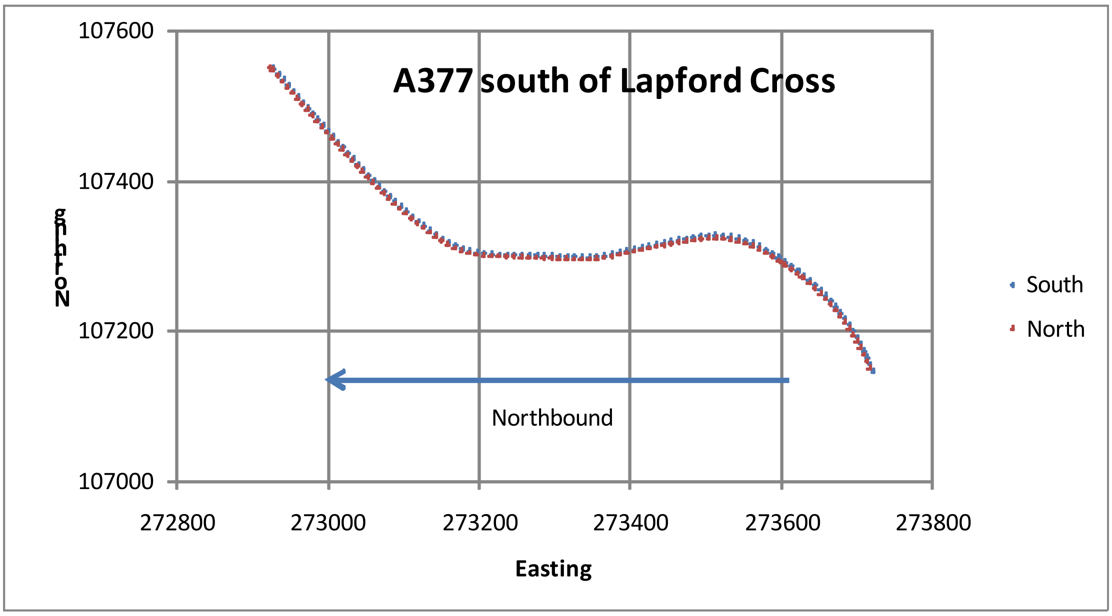


**Figure 6-1 SCANNER OSGR co-ordinates, A377, south of Lapford Cross**

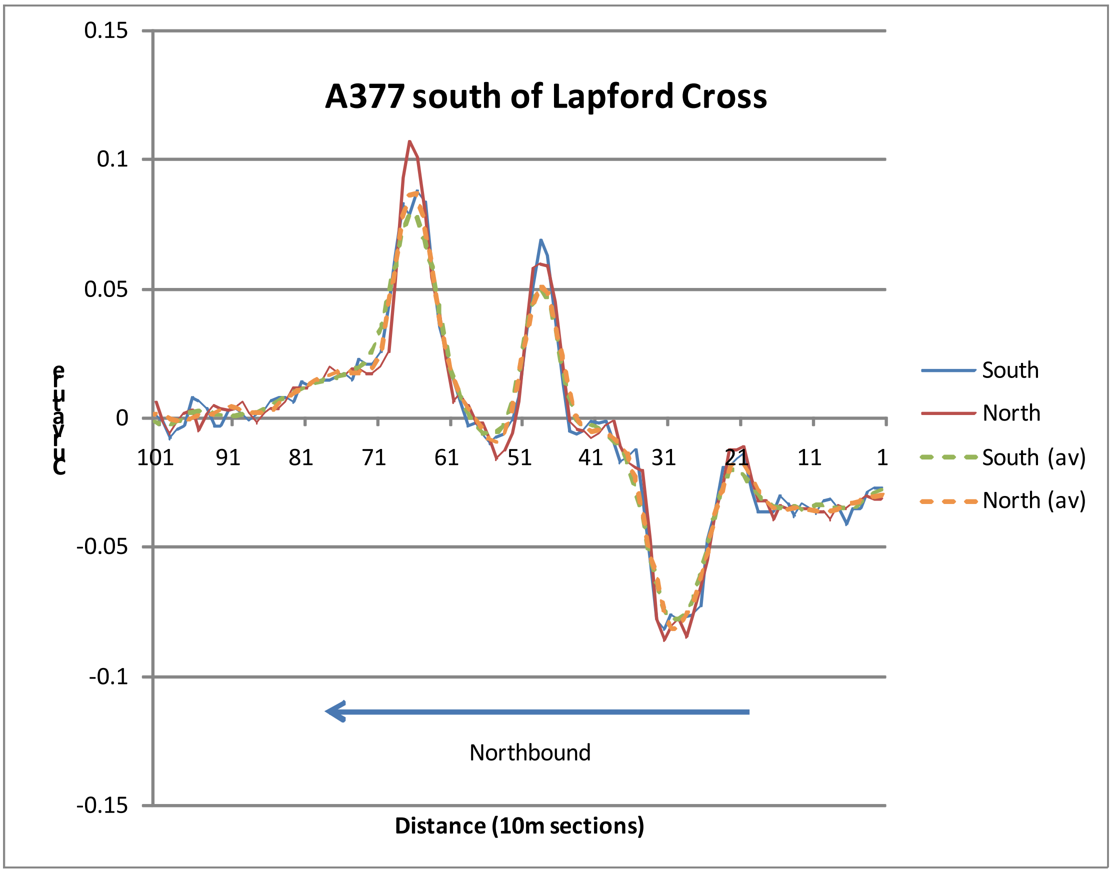


**Figure 6-2 comparing individual and averaged values of SCANNER curvature**

Therefore, when using the approach adopted by Devon to rate the bends, the results may be slightly more consistent if the moving average value of the radius of curvature is used, rather than simply the single highest point value, as this will reduce the effect of small variations in driving line. Another issue with using point estimates is that they are vulnerable to the effects of anomalous driving line events such as obstructions in the road, as illustrated in Figure 6-3 and Figure 6-4.

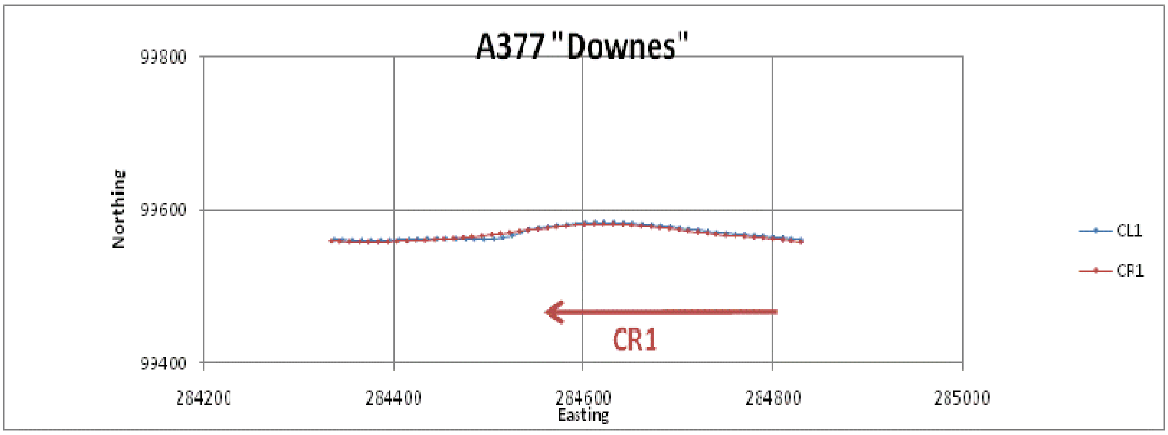


**Figure 6-3: SCANNER data GPS points at A377 'Downes' section. Note very slight deviation between blue and red points (different directions of survey vehicle travel) between easting 284400 and 284600. See next figure for translation of this into curvature values.**

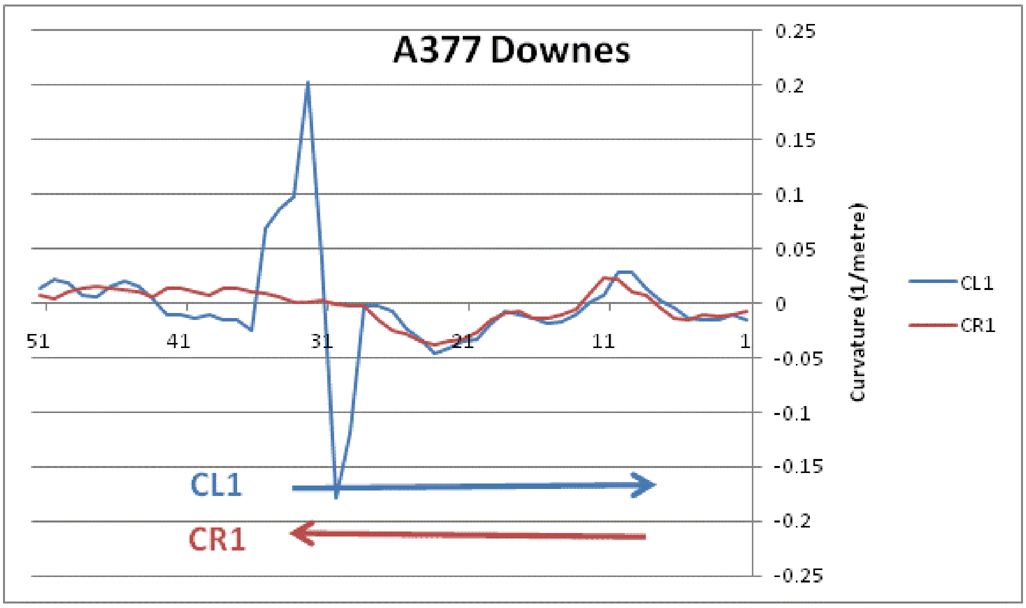


**Figure 6-4: Curvature values for SCANNER GPS data seen in Figure 6-3. This is best explained by assuming that the survey vehicle, when travelling in the CL1 direction, experienced a stationary object on their side of the carriageway and needed to negotiate this object by driving around it (see Appendix A for a description of the directional terms 'CL1' and 'CR1').**

In short, the anomalous curvature value at the point on the road shown in Figure 6-4 would show up as a very sharp bend when using point values for curvature to define bend risk scores. Although this kind of mistake can be removed by human intervention—it is 'obvious' to a human observer that the data do not reflect the road, but instead reflect some anomalous event in one direction when the road was being scanned—if a moving average method was used to calculate curvature then the effect would be to smooth out such events, and make the use of the SCANNER data more efficient.

## 6.2 Calculating other variables related to risk

Another thing to consider is that the approach taken by Devon County Council is based only on the raw data currently available in SCANNER (i.e. curvature and cross-fall values). This is, of course, an entirely sensible first step to establish whether or not the general approach holds any promise. However now that the promise of the general approach is established, it makes sense to consider if the approach can be refined further. It is entirely plausible that further analysis of the existing SCANNER variables may permit a more sophisticated and refined approach to assigning risk along a route. In short, it is possible that the model of risk can be made more valid by including other variables that can be calculated from the existing ones, or from the existing ones in SCANNER combined with other datasets. Sections 6.2.1 and 6.2.2 below briefly describe two such refinements (forward visibility, and road holding) that we believe are worthy of further research and development. Appendix E provides an illustration of first attempts at calculating these variables from the A377 SCANNER data, within the scope of this project.

These two separate issues of forward visibility, and safe road holding speed, are well understood and have formed the basis of rational engineering design of new road alignments for many years. For example, the Highways Agency DMRB Standard for Highway Link Design TD 9/93 gives recommendations for the geometric design of new trunk roads. These include the concepts of "design speed", "sight distance", "stopping sight distance", "horizontal alignment", "minimum curvature" and "superelevation", "vertical alignment", "vertical curves" and "crest curves". There is no equivalent Standard for the treatment of evolved roads, which frequently have radii of curvature well below the recommended minimum values in TD 9/93.

### *6.2.1 Forward visibility*

On many roads in Devon (and specifically the A377) one issue that needs to be accounted for when considering the risk score given to a bend is the forward visibility available to the driver. Due to the presence of hedges and other roadside features often the road is effectively 'tunnelled' at the sides, which influences the extent to which drivers can see the road ahead. It is entirely possible that the association observed between risk scores and speed choice in the instrumented vehicle drives was due to the fact that tighter bends will tend to have lower forward visibility, and drivers will moderate their speed accordingly to keep at their favoured level of task demand or risk.

There is no reason why forward visibility cannot be estimated directly from SCANNER data, along the entirety of route being surveyed. Forward visibility is an important consideration on sharp bends. Since it is also possible (given assumptions about the friction of the road surface and the reaction time of drivers to unexpected events) to estimate a safe stopping speed for a given forward visibility distance, it should then be possible to identify those parts of the route that represent this mismatch between safe speed and observed speeds directly from SCANNER data, without having to first define 'bends' along the route according to their curvature. Of course, research effort would be needed to develop algorithms to parse and analyse SCANNER data directly, and some human intervention would still be required to observe 'mismatch sites' to check assumptions (for example, in some cases hedges may be absent and afford a greater view than is estimated by the curvature data alone). Some kind of speed data would also be required to compare to the safe stopping speed estimates, although in principle local authorities could collect such data from studies similar (although on a smaller scale) to the one reported in Section 3. As instrumented vehicles become cheaper and easier to source, this kind of data collection need not be a large financial burden.

An example of how forward visibility might be calculated from the SCANNER data is presented in Appendix E. Some initial data from the trial drive section of the A377 showed that compared to the basic Devon County Council approach, a better fit was obtainable with the driver speed data. However further work would be required to establish how accurate the approach is in terms of repeatability for different road types (see Section 6.3).

### 6.2.2 *'Comfortable handling' speed*

Another variable that is important for safety on bends (especially for two-wheeled vehicles) is road holding. Again it is possible that this variable may be computed from SCANNER data, in the form of a 'comfortable handling' speed (see Appendix E). As with forward visibility, in principle this value can be calculated for the entire route, at 10m intervals along the road. Again, further work will be required to develop this approach, although an example of how it might be done is presented in Appendix E.

## 6.3 Limitations in applicability

The use of existing curvature and cross-fall information in SCANNER data may well provide a good starting point for assigning risk scores to bends on most local authority roads in the UK. However it is entirely possible that the baseline model will not transfer well to some kinds of road topography and geometry. For example, the link between driver speed choice and bend curvature on the A377 may arise largely because of the link between curvature and forward visibility on sharp bends, given the presence of road-side hedges that create a 'tunnelling' effect for most of the route. It is not clear whether the baseline model will transfer to those roads where there is much greater visibility through bends due to a lack of roadside vegetation or no very sharp bends. It is possible for example that when approaching bends with good forward visibility, drivers may rely much more on information derived from seeing 'past' the bend in question, rather than on the geometry of the bend itself, to assess risk. Therefore any attempt to assign bend risk using SCANNER may not represent the true risk present on such bends; the true risk present may be lower than expected (since drivers can see through the bend and therefore are less likely to be 'surprised' by something they did not expect), or of course may be higher than expected (due to drivers speeding up too much for the bend geometry, since they can see more of the road ahead).

To maximise the applicability of the general approach of using SCANNER data to assign risk scores to rural roads then, the potential improvements discussed in this section require further research effort in order that they can be developed. The key focus of this research effort should be in assessing the applicability of the various models of risk that can be built using SCANNER data to different road topographies, geometries, and other features of roads that are likely to vary with local highway authority area. Ultimately, the aim of such research should be to identify those variables that influence the applicability of the different models developed (e.g. basic curvature, forward visibility, road holding), so that appropriate models can be fine-tuned and produced for use by local highway authorities.

# 7 Conclusions and recommendations

## 7.1 Conclusions

The main conclusions drawn from the study are as follows:

1. The risk scores created by Devon County Council for the bends on the A377 correlated negatively and moderately to strongly with driver speed choice in the instrumented vehicle study. As risk scores went up, driver speed went down. This is what would be expected if the risk scores related to risk or task difficulty, since it is known that drivers vary their speed to control task difficulty.
2. Therefore we can conclude that using SCANNER data to define risk scores for bends, as a broad approach, has validity based on driver speed choice. It represents a pragmatic approach to defining risk scores for bends that can then be fine-tuned if necessary with collision data and other hazards such as junctions.
3. The driver speed data also suggested that drivers varied their speed on bends in response to the existing treatments on the A377. This suggests that Devon County Council's intention to treat the bends on the A377 with a more consistent signing and marking hierarchy is a sensible one that should have some impact on changing driver behaviour on the route.
4. In the questionnaire study, drivers responded to the signing and marking hierarchy with speed estimates in a way that suggested they perceived the hierarchy as expected; as the number of treatments increased, speed estimates went down, with almost all levels of treatment being significantly or nearly significantly different from all other levels in terms of speed estimates.
5. The analyses reported in this study (of both the behavioural data and the SCANNER data) represent only a fraction of what will be achievable over the longer term; a number of additional analyses are worthy of further research so that the general approach taken by Devon County Council can be assessed for further application outside of the current context in which it has been tested.

## 7.2 Recommendations

The key recommendations offered from this study are as follows:

1. Devon County Council should proceed with its use of SCANNER data and collision data to assign risk scores to the bends on the A377. However before final risk scores are decided, consideration should be given to adjusting the risk score on the basis of other potential sources of risk such as junctions on the bend.
2. Where there have been multiple collisions on a bend, these should be investigated for any common causal factors.
3. The resulting risk scores should be used as the basis of treatments in the signing and marking hierarchy developed by Devon County Council. It will be necessary to 'group' the risk scores to make six categories. Consideration will need to be given to the different ways in which this might be achieved.
4. The next step in the process should be a controlled 'before and after' evaluation of the new signing and marking hierarchy *in situ* on the A377. The guidelines in Section 5 of this document should be followed in this regard.
5. Further research should be focused on how to expand the broad SCANNER-based approach used by Devon County Council on the A377. A number of other issues present themselves as worthy of further research effort, including the 'smoothing' of SCANNER data by taking moving averages, and the calculation of other safety-relevant variables from SCANNER data such as forward visibility, road holding,

and gradient (see Section 6). Such work should have as its end objective a simple tool that can be used by local authorities to rate bends on their rural road directly from the SCANNER data; the cross-local-authority validity of the algorithms used will need to be validated.

6. We also recommend that Devon, and other local highway authorities, consider gathering ‘norms’ for speed data on major rural routes that are in need of treatments to address safety concerns. Such survey data need not be over-costly to collect using instrumented vehicles, and will provide an invaluable database to be used alongside road geometry and other information in setting priorities for site of high risk on rural roads.

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# Appendix A **Scanner data analysis**

## A.1 Introduction

This section summarises the SCANNER geometric data gathered on the A377 in Devon, as part of a wider investigation into improving driver (and other road user) safety. It describes how the data were coded for the analyses described in Appendix E.

## A.2 SCANNER survey data

To enable an investigation of alternative ways of analysing SCANNER data to rate bends, Devon provided a sample of SCANNER survey data for the whole of the A377, from the junction between the A377 and the A30 at Alphington near Exeter to the junction between the A377 and the A39 on the outskirts of Barnstaple. The parameters provided were:

- The three geometric parameters, gradient, cross-fall and radius of curvature.
  - The **Gradient** of the carriageway, measured as the inclination of the survey vehicle along the road, a positive gradient is uphill, a negative gradient is downhill. The value is a percentage to 2 decimal places.
  - The **Cross fall** of the carriageway measured as the inclination of the survey vehicle across the road, a positive value indicates the right of the vehicle is higher than the left (camber), a negative value indicates the left of the vehicle is higher than the right (super-elevation). The value is a percentage to 2 decimal places.
  - The **Radius of Curvature** of the carriageway, measured from the difference in direction of travel of the vehicle between the beginning and the end of the 10m sub section. A positive value indicates the road is curving to the left in the direction of travel, a negative value that the road is curving to the right. The value is reported in metres, with limiting values (for a nearly straight road) of -10,000m and +10,000m. [Some 600 or so of the values reported were +100,000. For consistency, these have all been reduced to +10,000].
- The survey speed of the vehicle, reported as kilometres per hour (km/h). The value is reported as an integer.
- The three positional parameters, Ordnance Survey Grid References (OSGR), easting, northing and elevation.
  - The **OSGR Easting**, reported as the centre of the 10m subsection.
  - The **OSGR Northing**, reported as the centre of the 10m subsection.
  - The **OSGR elevation** (altitude), reported as the centre of the 10m subsection.

These values are reported with 3 decimal places (i.e. location to the nearest mm) although the accuracy of location is generally only to within the nearest metre.

## A.3 Data referencing in UKPMS

The UK Pavement Management System (UKPMS) is the national standard for management systems for the assessment of local road network conditions and for the planning of investment and maintenance on paved areas of roads, kerbs, footways and cycle-tracks on local roads within the UK. (Chris Britton Consultancy, 2005, http://www.pcis.org.uk/index.php?p=6/12/0/detail,0,64).

In general, all pavement management systems consist of a representation of a road network divided into uniquely referenced road lengths. Against this network, it is possible to locate other data including condition data collected by visual or machine surveys and inventory such as construction details and width information. By applying rules to the condition data held against each section it is possible to identify potential maintenance treatments and these treatments can be prioritised by condition or in an order that will give best value for money in the long term.

Simplistically, in UKPMS the road network is divided into a number of disconnected sections. Each section has a start point and an end point. These may be (but do not have to be) specified as nodes. Within each section the "features", such as carriageway or footway, are described as being to the left or the right of the centreline, and are numbered conventionally across the section.

The SCANNER survey is normally carried out in the left most lane of the carriageway, in the normal direction of traffic. However, for historic reasons associated with visual condition surveys, UKPMS describes the majority of sections as having a "forward" and a "reverse" direction. Therefore the SCANNER survey consists of a "forward" survey in the lane designated as CL1 in the UKPMS section and a "reverse" survey in the lane designated as CR1 in the UKPMS section.

On the A377, the majority of the route (by length) consists of single carriageway with traffic in both directions. In these cases the UKPMS sections are continuous along the road, with CL1 (first carriageway lane on the left) and CR1 (first carriageway lane on the right). However, there are places where the carriageway divides into one way roads. In UKPMS segregated carriageways are always designated as having no centreline and running in one direction only. (The forward direction is usually the normal direction of traffic).

There are also some sections of dual carriageway. In UKPMS sections of dual carriageway are treated as segregated carriageways, each side has no centreline, and is referenced in one direction only, the normal traffic direction. Therefore there are two sections of parallel carriageway, both of which are referenced in the forward direction (CL1), even though they may run geographically in opposite directions.

Within each section, the chainage (distance along the section) is measured in metres, from the start point to the end point.

## A.4 Fitting survey data to the UKPMS network

When a SCANNER survey is carried out, the survey contractor is responsible for "fitting" the survey data to the UKPMS network. This is carried out in stages.

Firstly, the start and end points have to be marked on the data. Traditionally this is done by one of the operators in the survey vehicle identifying the physical location of the start of the section and pushing a button to insert a section marker in the data. Where sections run continuously, the start and end point are the same. But where there is a section of data that is not to be included in a survey (e.g. when traversing a roundabout) both a section end point and a following section start point may be required.

Then the data have to be matched to the network.

- The section start point may not lie exactly at the beginning of a 10m subsection, so the subsection is divided proportionally between the two sections which it straddles.
- Similarly, the section end point may not lie exactly at the end of a 10m subsection, so the subsection is divided proportionally between the two sections which it straddles.
- The number of data subsections measured by SCANNER within the section may not match exactly the length of the UKPMS defined section, because of errors in positioning the start and end points in the SCANNER data. In which case, the SCANNER data points within the section are stretched out or squeezed up, to distribute them evenly through the UKPMS section length, by reducing or increasing the length of some of the SCANNER data subsections by one metre. This is referred to as "rubber banding" and there are limits on the extent to which it is acceptable, before the SCANNER data must be rejected.
- Because the error in marking section start and end points is normally of the same order of magnitude, the proportional effect is far greater where the sections are comparatively short (less than 100m) and less where the sections are comparatively long (more than 1km).
- Experience has shown that manually entered start and end points can often be slightly out of position, by up to 20m or 30m, and occasionally 100m or more. Therefore matching up data that has been "fitted" to a UKPMS network can be very difficult, because the errors on one side of the road (CL1) can differ from those on the other (CR1), so data that appear to come from approximately the same place on the road (i.e. to within less than 10m) may be 20m, 30m or occasionally further apart.

The advantage of having positional data is that it is generally possible to position the geometric data with accuracy to within a few metres, allowing for the normal variability in GPS referencing.

## A.5 A note regarding UKPMS sections on the A377

For reasons associated with the Devon operational area boundaries, the definition of the A377 is divided in the UKPMS network definition near the centre, at Leigh Cross. The UKPMS forward direction is defined as running away from Leigh Cross in both directions (north and south) so that the CL1 and CR1 directions are not consistent along the full length of the A377.

Starting from the south eastern end of the A377, at the junction with the A30 at Alphington, the north western bound lane is (generally) CR1 and the SCANNER survey is in the "reverse" direction, as far as Leigh Cross, when the definition changes, and the survey continues in the "forward" direction as CL1.

Similarly, starting from the north western end of the A377, at the junction with the A39, the south eastern bound lane is (generally) CR1 and the SCANNER survey is in the "reverse" direction, as far as Leigh Cross, when the definition changes and the survey continues in the "forward" direction as CL1.

## A.6 SCANNER survey data

The data provided by WDM (exported from their data management system) came in the form of three spreadsheets in a workbook:

1. A377 2008 survey data

2. A377 2009 survey data
3. A377 section listing

### *A.6.1 A377 2008 survey data*

This consisted of a total of 6670 survey records (i.e. 10m subsections of SCANNER data); 6600 CR1 survey records from the CR1 carriageway lane and 70 CL1 survey records from the CL1 carriageway lane. All surveys were carried out on 21st May 2008. Each record contained:

| Item | Description | Source |
|---|---|---|
| Road name | A377 | UKPMS data |
| Section code | typically 5 digit numeric code of the form 40xxx or 41yyy | UKPMS data |
| XSP (cross sectional position) | either CL1 or CR1 | UKPMS data |
| Start metre | integer | UKPMS data |
| End metre | integer | UKPMS data |
| Survey date | 21st May 2008 | UKPMS data |
| Gradient | | SCANNER data |
| Cross fall | | SCANNER data |
| Curvature | actually radius of curvature | SCANNER data |
| Section length | | UKPMS data |
| Survey vehicle speed | | SCANNER data |
| OSGR Easting | | SCANNER data |
| OSGR Northing | | SCANNER data |
| OSGR Elevation | | SCANNER data |

### *A.6.2 A377 2009 survey data*

This consisted of a total of 6952 survey records (i.e. 10m subsections of SCANNER data); 6684 CL1 survey records from the CL1 carriageway lane and 268 CR1 survey records from the CR1 carriageway lane. Surveys were carried out on 13th May (6419 records) and 11th November 2009 (533 records). Each record contained the same information as the A377 2008 survey data.

### *A.6.3 A377 section listing*

This consisted of 175 separate records for each individual section. Each record contained:

| Item | Description |
|---|---|
| Road (name) | A377 |
| Section code | typically 5 digit numeric code of the form 40xxx or 41yyy |
| Section name | text, typically of the form "Morchard Road" |
| Section type | text, range of types listed below |
| Section length | metres, integer |
| Start node name | text, typically of the form "speed limit" or "Lapford Cross" |
| End node name | text, typically of the form "B3220 Winkleigh" or "Smallbrook (bus stop)" |

### A.6.4 UKPMS section types

The following section type descriptions were used:

| Type | Number of sections | Total length (m) |
|---|---|---|
| Bus lane & dual carriageway | 1 | 101 |
| Dual 2-lane | 9 | 666 |
| One way 1-lane carriageway | 8 | 880 |
| One way 2-lane carriageway | 2 | 165 |
| One way 3-lane carriageway | 1 | 37 |
| One way 4-lane carriageway | 2 | 213 |
| Single 2-lane carriageway | 152 | 64,865 |

### A.6.5 Reviewing the survey data

The two sets of survey data provided are (mostly) CR1 data from 2008 and CL1 data from 2009.

The Department for Transport requires local highway authorities to report the condition of their A roads each year based on SCANNER surveys carried out within the previous two years. For reasons of economy, most local authorities choose to survey half the length of their roads each year, giving full coverage over two years. Some authorities choose to do more. Some authorities choose to survey the roads in one direction one year, and the other direction the next. Other authorities choose to survey half the length in both directions one year, and the other half the following year.

As the data provided are (mostly) CR1 from a survey in 2008 and CL1 from a survey in 2009, it would appear that Devon has chosen to survey in one direction one year, and the other direction the other. The two survey data sets are compared in
Table A-1

**Table A-1: Comparing survey data sets between 2008 and 2009**

| | 2008 | 2009 | total |
|---|---|---|---|
| CL1 records | 70 | 6684 | 6754 |
| CR1 records | 6600 | 268 | 6868 |
| total | 6670 | 6952 | |

This shows an excess of CR1 data over CL1, which is the opposite of what would be expected, as CR1 can only be present on single carriageway roads, whereas CL1 data will predominate in one way systems and dual carriageways. Careful checking revealed that some of the CR1 data included in the 2009 data set duplicated CR1 data in the 2008 data set.

The two data sets were “cleaned” by removing the 2009 duplicate CR1 data. This left the following data for analysis:

**Table A-2: Comparing amended survey data sets between 2008 and 2009**

| | 2008 | 2009 | total |
|---|---|---|---|
| CL1 records | 70 | 6684 | 6754 |
| CR1 records | 6600 | 0 | 6600 |
| total | 6670 | 6684 | |
| UKPMS sections | | | 66,927m |

In theory, there should be a total of 6,693 SCANNER subsections of CL1 data, and potentially 6,487 SCANNER subsections of CR1 data. However, because of the potential to split subsections at section nodes, there could be an additional 170 or so extra subsections, indicating a possible maximum total of about 6,863 CL1 and 6,657 CR1 subsections. After removing the excess CR1 data, the quantities of remaining data are at least within the right range.

#### *A.6.6 Aligning the survey data*

All three sets of data records were provided sorted by section code order. As the section codes are not necessarily sequential, although the data within each section is sequential, there is not necessarily any continuity between sections. (The section listing provides information on how to sequence the sections, linking one section end node to the following section start node).

In principle, it would be possible to identify the order of the sections over four separate routes:

- From the start of the A377, at the A30 junction in Alphington to Leigh Cross. (Mostly CR1, with CL1 on dual carriageways and one way streets)
- From Leigh Cross to the end of the A377 at the junction with the A39 near Barnstaple. (All CL1)
- From the start of the A377, at the A39 junction near Barnstaple to Leigh Cross. (Almost all CR1 on single carriageway)
- From Leigh Cross to the end of the A377 at the junction with the A30 at Alphington. (All CL1)

It would then be possible to "chain" the data in sequence along the sections, and connect the data across the nodes.

In practice, this would be a very labour intensive and time consuming process, and the survey data within CR labelled sections would have to be "reversed" again to match the SCANNER survey direction, rather than the UKPMS network direction.

Alternatively, it is possible to sort the data using the OSGR co-ordinates. Simply plotting the Easting and Northing values of all the CL1 and CR1 records shows that the data fits on the road. Samples of the data can then be extracted and plotted at a smaller scale to illustrate conditions on the road. Figure A-1 shows an example at Spence Combe, midway between Crediton and Copplestone, on section 40230 (Barnstaple Cross, start node Quarry Foot Cross, end node Barnstaple Cross (W)). South of Leigh Cross, the CL1 (forward) direction is south and east, the CR1 (reverse) direction is north and west, illustrated with arrows.

This example shows how closely the data may be aligned, over a survey length of about 1.14 km, but it also shows that, in places, the data may be misaligned (for example where the blue and red markers are on the wrong sides of the road, relative to each other, as circled).

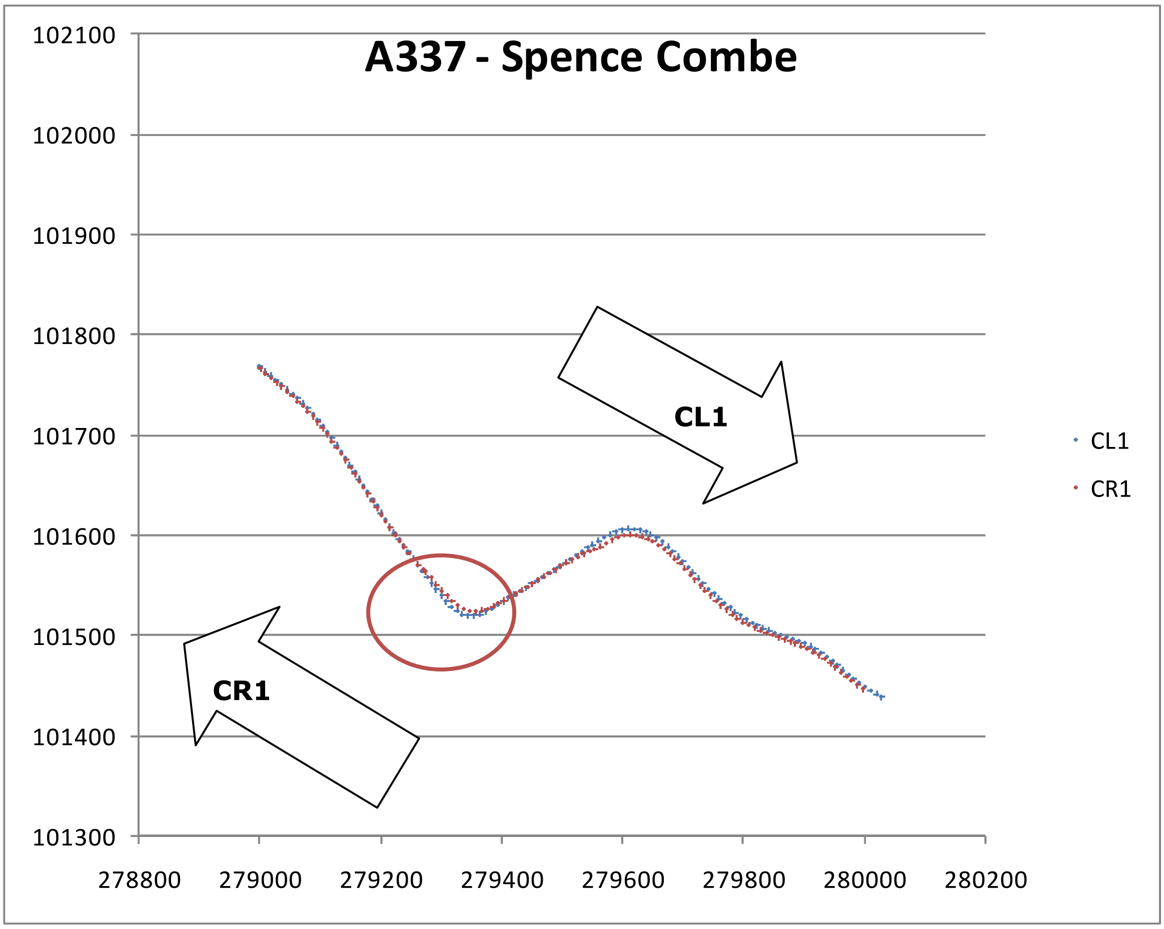



**Figure A-1 SCANNER OSGR co-ordinates, A377, at Spence Combe**

### *A.6.7 Analysing the data*

The data were re-organised into two spreadsheets within an Excel workbook, containing the survey data in sequence, one from the northbound carriageway (in sequence) and the other in the southbound carriageway (in reverse order) to make it easier to compare values between the two carriageways.

# Appendix B **Detailed review of Devon County Council approach and of bend safety literature**

This appendix contains a more detailed version of the content covered in Section 2. It is included here for completeness.

Devon County Council aims to develop a logical hierarchy for bend signing and marking that is linked to various factors, particularly curvature, so that the more severe the bend, the more the signing and marking encourages drivers to slow down and adopt the appropriate speed for the bend. In this section the wider literature and knowledge on bend risk and on bend treatments are considered. The approach being proposed by Devon County Council for use on the A377 is then reviewed against this knowledge, and recommendations are made.

Pratt and Bonneson (2008) suggest that there are two types of collisions on bends. In the first, drivers do not perceive the bend whether because of distraction or impairment and do not slow down. This type of collision can occur whatever the severity of the bend. In the second, drivers fail to realise the severity of the bend and do not slow down enough. It is in this latter case that the choice of signing and marking will be important. Various authors (e.g. Retting & Farmer, 1998) point out the importance of consistency in signing and marking; if several bends of similar severity have similar signing and are followed by a more severe bend with the same signing, then drivers may be caught out and may not slow down sufficiently.

## B.1 Factors affecting risk on bends

There are a number of factors that affect collision risk on bends. Road engineering factors are:

- Radius of curvature of bend
- Speed of approach determined by:
    - forward visibility
    - road width
    - verge width
    - vertical curvature
    - bendiness of the road
- Degree of superelevation
- Skid resistance of the road
- Signing and marking

(see Chapter 4 of the Traffic Signs Manual, DfT, 2004; Barker, 1997; Charlton & de Pont, 2007; Kanellaidis, 1995).

Other factors affecting collision risk relate to the driver's speed choice e.g. weather, vehicle type and speed, driver alertness (e.g. whether distracted or under the influence of alcohol or drugs) and whether the driver is familiar with the road (Barker, 1997). Both Charlton and de Pont (2007) and Stewart and Chudworth (1990) point out that risk is also increased by deceptive bends. Stewart and Chudworth (1990) suggest that the deceptiveness can result from the use of a transition curve between the straight road and the circular bend and that creating uniform curvature on tight bends can be a highly cost effective means of reducing collisions. However, their results are limited to only three bends.

## B.2 Speed on the approach to a bend

The Highways Agency DMRB TD 9/93 Highway Link Design Standard sets out a scheme for trunk roads that is related to the "design speed" of the road. This gives "desirable minimum" values for horizontal curvature, with associated superelevation, and for stopping sight distances. For roads not built to this standard, there are values for one and two design speed steps below the desirable minimum for horizontal curvature and one step below for stopping sight distance, and lower values can easily be extrapolated.

The "design speed" of an existing road is usually taken to be a typical speed, determined either by driving along the road or from the mean of 85$^{th}$ percentile speed in free flow conditions on a straight section of road.

The approach speed or tangent speed to a bend should be measured directly at a point in advance of the bend (e.g. Herrstedt & Greibe, 2001), although for trunk roads it has often been assumed to be equal to the design speed (Kerman *et al*, 1982), since drivers only reduce their speed by a small amount on bends that are built to TD 9/93.

## B.3 Speed on the bend itself

The speed on a circular curve is approximately related to its radius through the equation:

$$V^2/R = g\ (e + f) \qquad (1)$$

where R is the radius of the bend (m)
g is the acceleration due to gravity (9.81 m/sec$^2$)
e is the superelevation
f is the coefficient of friction
$V^2/R$ is the lateral acceleration or side friction demand

Here, speed is measured in metres per second. With V in miles per hour and g taken as 9.81, equation (1) becomes:

$$V^2/(127R) = e + f \qquad (2)$$

The coefficient of friction f depends on the road surface condition, the tyres of the vehicle and its speed but the maximum value is generally assumed to be about 0.8 when the road is dry. The superelevation e is usually between 2.5 and 5%. However, there is a limit to the lateral acceleration that drivers will tolerate and they tend to brake before this limit is reached in order to maintain driver comfort. For cars, except where there is poor skid resistance or under extreme weather conditions, it is driver discomfort that is the limiting factor rather than the coefficient of friction. For heavy vehicles, rollover occurs before the limit of skid resistance is reached (lateral acceleration of about 0.35g).

In TD 9/93, the desirable minimum radius for a bend is defined as that occurring when the lateral acceleration at the design speed is 0.11g, half the threshold of discomfort, taken to be 0.22g.

Equations (1) and (2) assume that drivers follow a circular curve. In reality, the estimated speed on the bend may differ from the measured speed because drivers may cut the corner if the bend is sharp, taking a path with a greater radius of curvature, or they may have to make an abrupt change to their path and so follow a tighter radius than expected.

Various authors have derived equations for the speed $B_s$ on a bend of radius R (see e.g. McLean, 1995), that are based solely on the curvature of the bend (1/R), for example:

$$B_s = \alpha - \beta\,(l/R) \qquad (3)$$

where α and β are parameters determined via regression. In the UK, the formula for bend speed developed in the background research for TD 9/93 (see Kerman *et al*, 1982) depends strongly on the approach speed, $A_{s,}$ rather than just the curvature of the bend and is:

$$B_s = A_s\,(1 - A_s^2/400R) \qquad (4)$$

On roads built to TD 9/93, even at the absolute minimum radius in TD 9/93, this implies a maximum speed reduction of 5%. On local highway authority roads, the bend may be several design speed steps below the absolute minimum in TD 9/93 and the reduction in speed will consequently be greater. For example at 3 design speed steps below absolute minimum, the predicted reduction in speed for the bend is 20%.

Pratt and Bonneson (2008) point out that driver discomfort occurs at lower thresholds of lateral acceleration with increasing speed but that drivers try to maintain their tangent speed and will therefore tolerate higher levels of discomfort at speed. As a result, drivers will drive much faster round a bend of the same radius if the approach speed is high than if it is low (as shown by equation (4)).

As an example, consider a bend with 100m radius. With an approach speed of 80km/h, the speed on the bend predicted by equation (4) is 67km/h, whereas on a road with an approach speed of only 60km/h, the same bend would be traversed at 55km/h The speed predicted by equation (2) would depend on the level of comfort the driver will tolerate on the bend. Assuming a high value of 0.33 for $V^2/(127R)$ gives a predicted speed of 65km/h, whereas assuming a rather lower value of 0.22 gives a speed of 53km/h.

Lee *et al* (2000) in Korea proposed that speed on a bend is determined by forward visibility. They suggested that drivers slow down until their forward visibility is equal to their stopping sight distance as they approach and traverse the bend and then accelerate to their desired speed as visibility increases. They calculated the minimum available sight distance from the radius of curvature, the lane width and the lateral clearance to the nearest obstacle and assumed that this is equal to the stopping sight distance at this point. Charlton and de Pont (2007) point out that this method gave good agreement with measured speeds only for tight radius bends (less than 300m) suggesting that forward visibility is not the limiting factor at higher speeds.

A 10mph (15km/h) reduction between the approach speed and the bend speed has sometimes been taken as the criterion for eliminating a bend (e.g. Lee *et al*, 2000, Charlton and de Pont, 2007).

## B.4 Effect of vehicle type

Heavy goods vehicles need a longer distance to stop than cars and their harder tyres and higher centre of gravity mean that they will roll over at speeds much lower than those at which they will begin to slide, the opposite of what happens for cars. The rollover stability margin of vehicles is increased by the use of superelevation and this is particularly important for heavy vehicles.

Cars tend to slide at lower values of lateral acceleration than they will roll over, but the coefficient of friction only becomes important when skid resistance is low or there are adverse weather conditions.

Motorcycles have a much greater need for a high coefficient of friction from the road surface than do cars (IHIE Guidelines for Motorcycling) and this might indicate the need for high friction road surfacing at a bend with collisions involving motorcyclists. Like heavy goods vehicles, they are also much more affected by superelevation than are cars.

## B.5 Bend treatments

### *B.5.1 Signing and marking*

Because of the many factors affecting risk on a bend, there is no single convention for signing and marking a bend. However there are a number of treatments that have been used, and these are reviewed here.

#### *B.5.1.1 Warning signs and advisory speed signs*

Warning signs are intended to alert the driver to the increased risk, but are not always effective (e.g. Zador *et al*, 1987, cited in Retting & Farmer, 1998), possibly because of inconsistencies in their use. Most of the research on warning signs was undertaken many years ago and showed large benefits on severe bends at that time. This type of signing is now the norm.

In the UK, a bend warning sign should be used "to give advance warning of a bend which a driver might find difficult to negotiate without slowing down and the severity of which cannot easily be seen either by day or by night" (Traffic Signs Manual Chapter 4). However, there is no fixed requirement for when a sign is required.

Many countries make use of warning signs that include an advisory speed, generally taken to be the maximum speed for safely negotiating the bend in a passenger car in good weather conditions. However, as Donald (1997) points out, the inevitable safety margin required leads to some drivers considerably exceeding this speed. The setting of advisory speeds needs to be undertaken in a consistent manner so as not to catch out the driver. Even if the speed is realistic initially, there may be a need to periodically review it, in order to allow for changes in vehicle performance or driver behaviour over time. This type of sign is standard practice in the US, Australia and New Zealand but is not widely used in the UK where the recommendation is to use them sparingly, following research in the 1970s by Rutley (1972). Some European countries use a lower speed limit for a severe bend in preference to an advisory speed.

The US has a system of signing requirements in the latest version of the Manual on Uniform Traffic Control Devices (MUTCD, 2009) based on the difference between the speed limit (or the prevailing speed on the approach to the bend) and the advisory speed for the bend. Warning signs and advisory speed plates are recommended if the difference is at least 5mph and required if it is at least 10mph. The MUTCD also includes advice on how far in advance of the bend to locate signs, based on the design speed of the road.

#### *B.5.1.2 Chevron signs*

In the UK, chevron signs are intended to supplement the bend warning sign "where a bend sign alone would not be a sufficient warning" (Traffic Signs Manual Chapter 4). The sign should include at least two chevrons, with more on longer bends. Research for trunk roads using a driving simulator (Taylor *et al*, 2002) suggested that one long sign with four chevrons was more effective than four single chevron signs spaced along the approach to the bend. However, in practice this is likely to require engineering judgement at the site in question.

In the US, chevron signs and/or a large direction arrow are recommended if the difference between the prevailing speed on the approach and the advisory speed is at least 10mph and required if it is at least 15mph.

*B.5.1.3 Delineation*

Channelization on bends is intended to encourage drivers to slow down and guide them round the bend. In the UK, the centre white line becomes a warning line or a double white line, depending on the forward visibility. It may be emphasized by the use of 1m wide central hatching if the road is sufficiently wide to accommodate this, and is particularly aimed at reducing head-on collisions.

Intelligent road studs are a measure intended to reduce night time collisions by enhancing lane markings and can potentially detect and warn of hazards ahead. However, although various pilot trials have been proposed (e.g. by Faber Maunsell, 2005, for the Highways Agency) no results are reported in the literature.

Continuous white edge lines may be used to help delineate the bend and should be retro-reflective to improve night time conspicuity. Marker posts on the outside of a bend are another method of delineation. The use of marker posts ("post mounted delineators") is recommended in the US by the MUTCD as being particularly effective at night or in adverse weather conditions as they remain visible when there is snow on the road.

*B.5.1.4 SLOW markings*

In the UK, the word SLOW on the carriageway may be used to complement a bend warning sign and may be repeated if the bend is particularly hazardous (Traffic Signs Manual, Chapter 5).

*B.5.1.5 Bar markings*

Red bar markings on the approach to bends have been shown to reduce speeds by between 1 and 7mph at a small number of sites (unpublished research by TRL). However, it is not known to what extent this benefit is maintained over time. Yellow bar markings on the approach to roundabouts are very effective, acting principally as an alerting device. However, their use should be reserved for roundabouts.

*B.5.1.6 Rumble strips or areas*

Rumble strips or areas can be effective initially, but tend to become less so over time since they are less uncomfortable when traversed at higher speeds (Webster and Layfield, 1993) – an effect similar to that at cattle grids. Their other main disadvantage is that they are noisy and therefore cannot be used near housing. Webster and Layfield present results for two bends. Following installation, both bends showed a reduction in collision frequency, based on very small numbers. One of the bends had an initial reduction of 2mph in 85$^{th}$ percentile speed, which was not maintained when the strips were modified to a lower height because of complaints about noise. There was no speed data for the other bend. Barker (1997) reported on one site where over the year following installation, the mean speed of light vehicles on the apex of the bend was reduced by 3mph.

*B.5.1.7 Vehicle activated signs*

Winnett and Wheeler (2002) investigated the effect of vehicle-activated signs that display a bend warning sign when a vehicle is travelling above a certain threshold speed (set at the 50$^{th}$ percentile speed) at three rural bends. The signs were located between 50m and 100m in advance of the apex of the bend. Winnett and Wheeler found a reduction in mean speed of between 2 and 7 mph after one month. There was no evidence that drivers were becoming used to these signs, but there are anecdotal reports from some local authorities that the benefits of more recent installations are lower.

*B.5.1.8 WYLIWYG remedial measure for motorcyclists*

A remedial measure for motorcyclist collisions is the WYLIWYG ("where you look is where you go") system devised by Buckingham County Council, although the testing to date has been minimal. The measure involves the use of hazard marker posts deliberately positioned to lead riders' eyes to the vanishing point of the bend. Buckinghamshire County Council reports great benefits on a small number of bends, but the scheme does not appear to have been tested more widely.

## B.6 Classifying bends according to risk

### *B.6.1 Transport Scotland (Wither, 2006)*

Wither (2006) used the radius of curvature values in TD 9/93 as a means of classifying bends on single carriageway trunk roads in Scotland in a consistent way in order to devise a scheme for signing and marking bends to assist drivers. He adopted radius of curvature values that are between one and four design speed steps below the desirable minimum values given in TD 9/93. He did not mention the cross fall except to say that sites with poor superelevation require individual attention. The speed of approach to a bend will be related in part to the design speed of the road, but is not otherwise taken into account. Although Wither mentioned the importance of maintaining a good road surface and suggested using skid resistant surfacing especially at the most severe bends, he does not include skid resistance in his categorisation.

Wither has a set of signing and marking corresponding to each of the five radius-of-curvature categories (A to E) which steadily increase in risk with the severity of the bend, as shown in Table B-1. His values for the radii of curvature that define the categories depend on the design speed of the section of road concerned.

**Table B-1: Signing and marking for categories proposed by Wither**

| Category | Radius of Curvature R | Proposed Signing | Proposed Marking |
|---|---|---|---|
| A | DM> R > 1 DSSBDM | None | Edge lines and centre line |
| B | 1 DSSBDM > R > 2 DSSBDM | Hazard marker posts at 9m intervals round apex of bend | As A |
| C | 2 DSSBDM > R > 3 DSSBDM | As B + bend warning sign | As B |
| D | 3 DSSBDM > R > 4 DSSBDM | As C + chevron warning sign | As C plus SLOW marking adjacent to sign |
| E | 4 DSSBDM > R | As D | As D with additional SLOW marking at intermediate position |

DM – Desirable minimum radius of curvature
DSSBDM – Design speed step below desirable minimum

### *B.6.2 Herrstedt and Greibe (2001)*

Herrstedt and Greibe (2001) define bend categories according to kinetic energy using the formula ½ M $V^2$ where M is the mass of the vehicle and V is its speed. The need for drivers to slow down to negotiate a bend from the approach speed to the "design speed" for the bend (here the design speed is the safe speed for driving round the bend, defined below, rather than that defined in TD 9/93) leads to a change in kinetic energy $\Delta E$ of:

$$\Delta E = \tfrac{1}{2} M V^2_{approach} - \tfrac{1}{2} M V^2_{design} \qquad (5)$$

At high speeds, a relatively small reduction in speed requires the same change in energy as a larger change does at lower speeds. Bend categories are defined by changes in kinetic energy and the scheme has been calibrated in Denmark and France, but actual boundaries are not reported. There are five categories. The proposed signing and marking scheme is shown in Figure B-1, where category A has very slight risk and category E has very high risk.

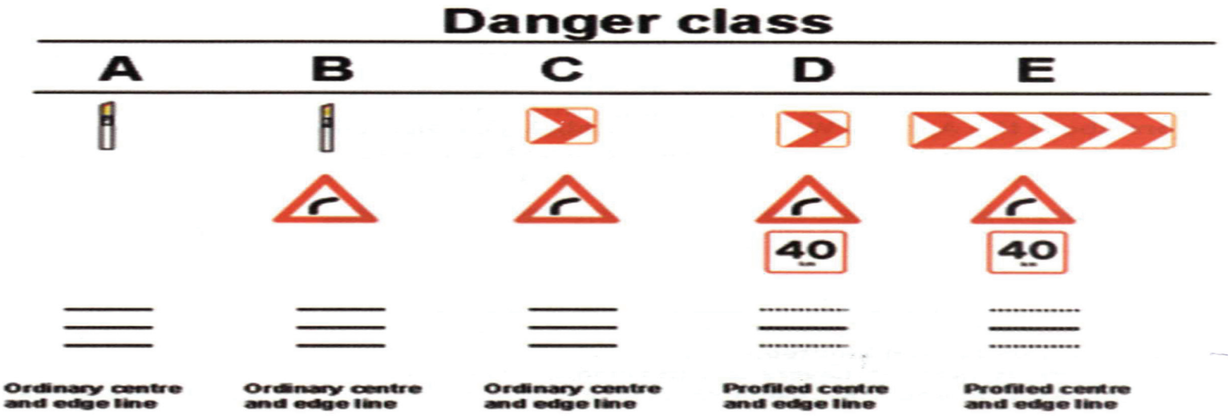



**Figure B-1: Signing and marking in Herrstedt and Greibe scheme (taken from Herrstedt and Greibe, 2001)**

Figure B-2 shows the categories as a function of approach and (bend) design speeds.

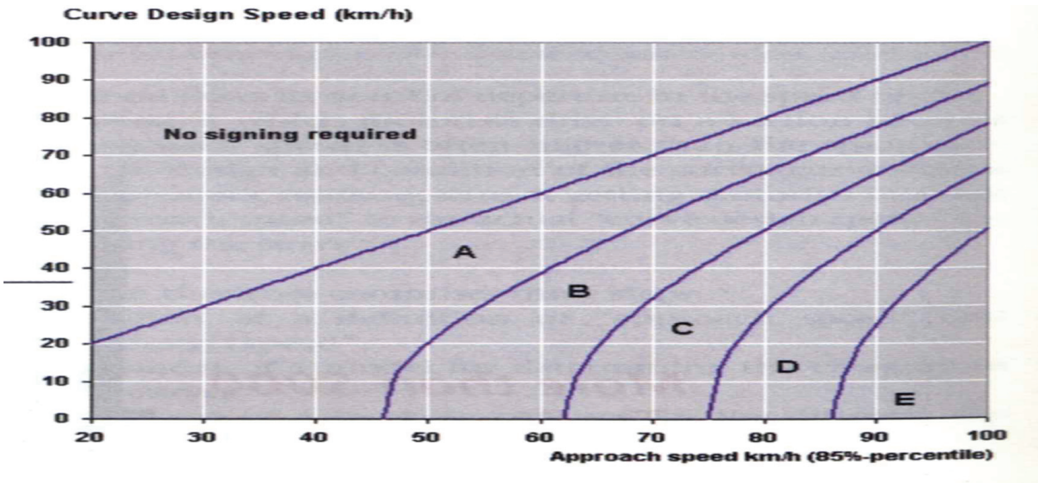



**Figure B-2: Bend categories as a function of speed (taken from Herrstedt and Greibe, 2001)**

Herrstedt and Greibe define the bend design speed $V_{Design}$ as in equation (1) and state that this is the speed at which the bend can safely be negotiated. They define the approach speed as the 85$^{th}$ percentile free speed, measured at a distance of between 150m and 250m before the bend.

The categories are adjusted for practical use by assigning a bend to a higher category if any of the following conditions holds:

- Insufficient forward visibility
- Bend is difficult to “read” e.g. with regard to sharpness or length
- Bend has a small radius after a long straight section
- Bend has an irregular radius
- Bend occurs just after a sharp fall in gradient
- Hazards close to the road that cannot be removed
- Bend with high collision frequency

A bend can be assigned to a lower category if for example the approach speed turns out to be lower than expected. One disadvantage of these categories is that if the approach speed is low, the higher risk categories would only be reached following the practical adjustments above.

### *B.6.3 Glennon (2003)*

Glennon (2003) criticised the MUTCD use of the difference between the speed limit and the advisory speed in the US (see above) on the grounds that not only is there difficulty in determining a suitable advisory speed, but also that this approach ignores “several factors related to the dynamics of the vehicle and driver tolerances to lateral acceleration”. He proposed an alternative scheme for signing and marking based on lateral acceleration – see Table B-2. As stated above, a lateral acceleration of 0.3g or less is generally considered comfortable for car drivers. Where the lateral acceleration exceeds 0.35g, there is a danger of heavy goods vehicle rollover.

**Table B-2: Guidance for Curve Signing (taken from Glennon, 2003)**

| **Lateral acceleration, *g*** | **Suggested Signing Treatments** | **Differential, *g*** |
|---|---|---|
| 0.19 or less | None | 0.00 |
| 0.20–0.23 | Curve warning sign | 0.01–0.04 |
| 0.24–0.27 | Curve warning sign, advisory speed plaque | 0.05–0.08 |
| 0.27–0.30 | Redundant curve warning signs and advisory speed plaques | 0.08–0.11 |
| 0.30–0.34 | Redundant curve warning signs and advisory speed plaques, chevrons | 0.11–0.15 |
| 0.35 or more | Other measures to reduce speed limit, rebuild curve, etc | 0.16 or more |

### *B.6.4 Proposed Devon County Council classification system*

The Devon County Council bend classification system is based on radius of curvature of the bend, the cross fall, and the collision history of the bend. Devon County Council has adopted the radius of curvature values proposed by Wither that correspond to a TD 9/93 design speed of 85km/h, shown in Table 2-1.

The Devon County Council scoring system is described in Section 2.2. and its application to the A377 in Section 2.2.1

In practical terms, the Devon scoring system can be thought of as an extension to the Wither scheme. It is also similar to the approach taken by Herrstedt and Greibe (2001), with the five suggested road curvature values giving the initial category and the bend being moved to a higher category if there is substandard superelevation or a history of collisions. Because there are only five curvature categories, it is likely that Category C6 will indicate a severe bend with either a poor collision history or substandard superelevation or both.

One consideration for signing and marking schemes is whether the choice of signing and marking for the different categories is at a level appropriate to the risk associated with the bend. It is also important that the categories can clearly be distinguished by drivers. There needs to be a steadily increasing emphasis on making the bend more evident to drivers as categories increase. It should be noted that in the Devon scheme categories C4 and C5 can only be distinguished by the driver if coloured anti-skid surfacing is used. There is anecdotal evidence that visible skid-resistant surfacing makes some drivers speed up, although it should also increase awareness of the bend. Another issue that needs be clarified is how S-bends will be treated.

In the questionnaire survey described in Section 4, there was difficulty in distinguishing the presence of a chevron. However, this is unlikely to be the case in a real world situation.

# Appendix C Additional details relating to the instrumented vehicle study to examine driver speed choice

This Appendix gives some more detail on the method, analysis and results from the instrumented vehicle study (Section 3 gives headline findings).

## C.1 Method

### *C.1.1 Participants*

Participants were recruited from the local area, and the sample was stratified so as to be similar in terms of age and gender proportions to people who had been involved in collisions on the A377, outside of settlements, between 1/10/2004 and 1/10/2009. Tables C-1 and C-2 below show the proportions of genders and ages in these two groups.

**Table C-1: Ages and genders of people involved in collisions outside of settlements on the A377, between 1/10/2004 and 1/10/2009**

| | Age 24 yrs or less | Age between 25 and 38 yrs | Age between 39 and 53 yrs | Age 54 yrs or more |
|---|---|---|---|---|
| Male | 40 | 31 | 39 | 31 |
| Female | 15 | 16 | 12 | 18 |

**Table C-2: Ages and genders of sample**

| | Age 24 yrs or less | Age between 25 and 38 yrs | Age between 39 and 53 yrs | Age 54 yrs or more |
|---|---|---|---|---|
| Male | 7 | 5 | 6 | 4 |
| Female | 3 | 2 | 2 | 2 |

### *C.1.2 Equipment*

The camera used for video (linked to GPS signal from camera itself) was Janus V2. The in-vehicle data recorder (IVDR) was supplied by Airmax specifically for this project, and was based on the Airmax v7.4.4 data logging software.

### *C.1.3 Procedure*

The consent form and information sheet given to participants before each drive are reproduced on the following pages. The instructions given to participants in the car are as described in Section 3.2.4.

**Devon Country Mile Project – A377 study**

**Participant information sheet**

The A377 study for which you have volunteered is designed to assess what local people think of the A377. By gathering the opinions and perceptions of local people who use the A377, we can learn more about what improvements are needed to the road, in addition to regular maintenance.

You will be asked to drive a section of the road with a researcher present in the car. The purpose of the drive is to give you experience of the A377 (either in the day or at night) so that it is fresh in your mind when we ask you later about your perceptions and opinions of the A377. You will also be asked to complete a short questionnaire.

If you have any questions you can ask the researcher now. Then you will complete a consent form, and will take part in your drive, and interview/questionnaire session.

## WRITTEN CONSENT FORM

PLEASE **WRITE YES** OR **NO** IN THE SPACE PROVIDED

| | YES or NO |
|---|---|
| Have you read the Participant Information Letter? | |
| Have you had an opportunity to ask questions about the study? | |
| Have you received satisfactory answers to all your questions? | |
| Have you received enough information about the study? | |
| Do you understand that you are free to withdraw from the study... | |
| ...at any time? | |
| ...without having to give reason for withdrawing? | |

**You should only agree to take part in this study when all your answers to the above questions are yes**

| | |
|---|---|
| Do you agree to take part in this study | |

Participant Name: ______________________ Signature: ______________________

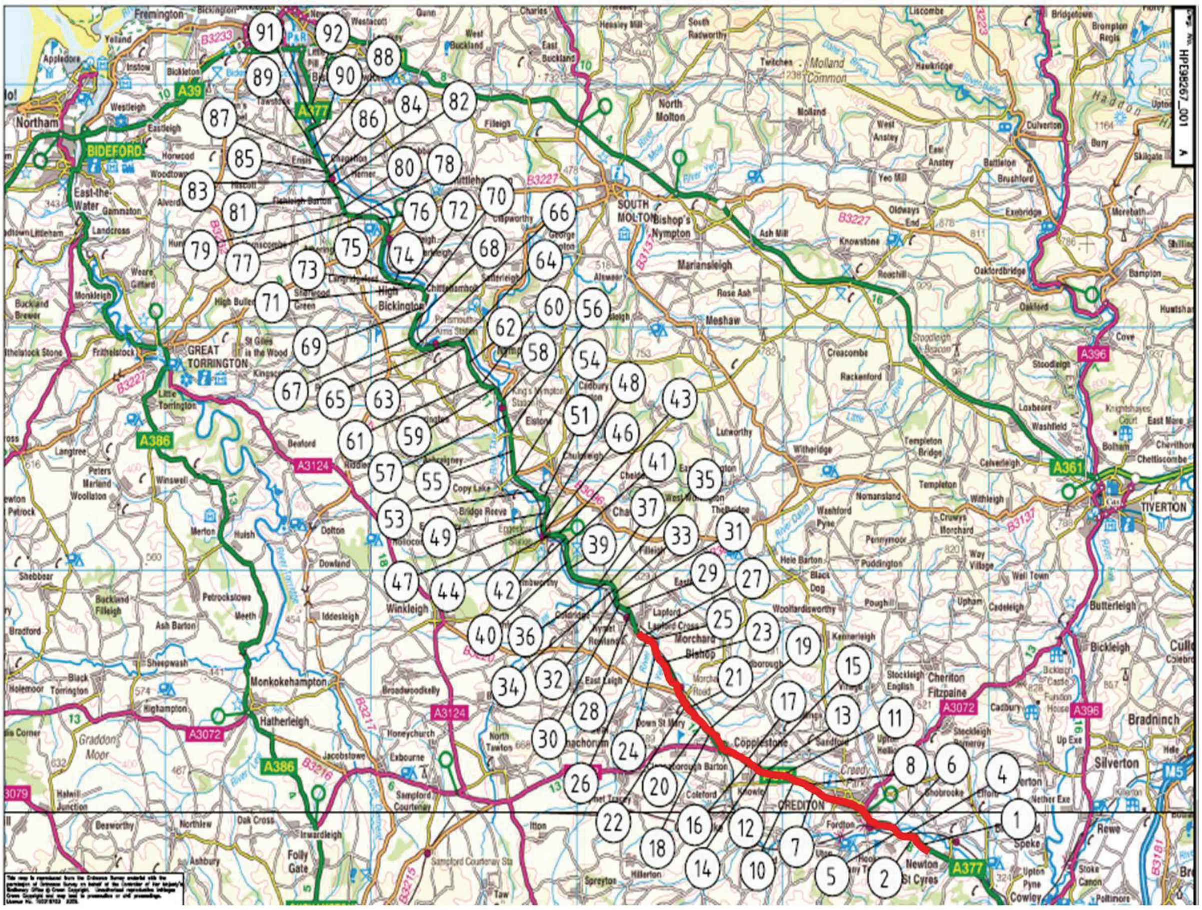
Date: ________________

Trials Manager: ______________________ Signature: ______________________

Date: ________________

*Please complete and sign this consent form for TRL*

The trial drive route is shown below in Figure C-1, overlaid on a map of the entire A377 Devon Country Mile Project area. The trial drive route is shown in red, between Newton St Cyres and Lapford.




## C.2 Analysis and results

### *C.2.1 Note on analysis*

All speed data and risk scores were explored in SPSS (v14) to assess whether the parametric assumption of normal distribution was met. In all cases except four, tests of normality confirmed that the variables were normally distributed and that therefore the use of parametric (Pearson's) correlational tests were appropriate. In the four cases where normal distributions were not apparent, non-parametric (Spearman's) correlations were run and confirmed the broad pattern of results.

Correlations are shown in Tables C-3 to C-10.

**Table C-3: Correlations (Pearson's r) between speed, risk score ('Risk'), risk score with collisions removed ('RisknoAc'), risk score with collisions removed and junctions added ('RiskJunc'), risk score with collisions removed and junctions added and treatments added ('RiskFeat') and the number of different treatments ('feat') – daytime northbound data**

| | | Speed | Risk | RisknoAc | RiskJunc | RiskFeat | Feat |
|---|---|---|---|---|---|---|---|
| Speed | Pearson Correlation | 1 | -.632(**) | -.652(**) | -.659(**) | -.683(**) | -.601(**) |
| | Sig. (2-tailed) | | .001 | .000 | .000 | .000 | .001 |
| | N | 25 | 25 | 25 | 25 | 25 | 25 |
| Risk | Pearson Correlation | | 1 | .893(**) | .829(**) | .793(**) | .633(**) |
| | Sig. (2-tailed) | | | .000 | .000 | .000 | .001 |
| | N | | 25 | 25 | 25 | 25 | 25 |
| RisknoAc | Pearson Correlation | | | 1 | .922(**) | .835(**) | .620(**) |
| | Sig. (2-tailed) | | | | .000 | .000 | .001 |
| | N | | | 25 | 25 | 25 | 25 |
| RiskJunc | Pearson Correlation | | | | 1 | .921(**) | .700(**) |
| | Sig. (2-tailed) | | | | | .000 | .000 |
| | N | | | | 25 | 25 | 25 |
| RiskFeat | Pearson Correlation | | | | | 1 | .923(**) |
| | Sig. (2-tailed) | | | | | | .000 |
| | N | | | | | 25 | 25 |
| Feat | Pearson Correlation | | | | | | 1 |
| | Sig. (2-tailed) | | | | | | |
| | N | | | | | | 25 |

** Correlation is significant at the 0.01 level (2-tailed).

**Table C-4: Correlations (Pearson's r) between speed, risk score ('Risk'), risk score with collisions removed ('RisknoAc'), risk score with collisions removed and junctions added ('RickJunc'), risk score with collisions removed and junctions added and treatments added ('RiskFeat') and the number of different treatments ('feat') – daytime southbound data**

| | | Speed | Risk | RisknoAc | RiskJunc | RiskFeat | Feat |
|---|---|---|---|---|---|---|---|
| Speed | Pearson Correlation | 1 | -.429(*) | -.618(**) | -.592(**) | -.778(**) | -.729(**) |
| | Sig. (1-tailed) | | .016 | .000 | .001 | .000 | .000 |
| | N | 25 | 25 | 25 | 25 | 25 | 25 |
| Risk | Pearson Correlation | | 1 | .839(**) | .768(**) | .677(**) | .403(*) |
| | Sig. (1-tailed) | | | .000 | .000 | .000 | .023 |
| | N | | 25 | 25 | 25 | 25 | 25 |
| RisknoAc | Pearson Correlation | | | 1 | .908(**) | .758(**) | .405(*) |
| | Sig. (1-tailed) | | | | .000 | .000 | .022 |
| | N | | | 25 | 25 | 25 | 25 |
| RiskJunc | Pearson Correlation | | | | 1 | .838(**) | .453(*) |
| | Sig. (1-tailed) | | | | | .000 | .012 |
| | N | | | | 25 | 25 | 25 |
| RiskFeat | Pearson Correlation | | | | | 1 | .866(**) |
| | Sig. (1-tailed) | | | | | | .000 |
| | N | | | | | 25 | 25 |
| Feat | Pearson Correlation | | | | | | 1 |
| | Sig. (1-tailed) | | | | | | |
| | N | | | | | | 25 |

* Correlation is significant at the 0.05 level (1-tailed).
** Correlation is significant at the 0.01 level (1-tailed).

**Table C-5: Correlations (Pearson's r) between speed, risk score ('Risk'), risk score with collisions removed ('RisknoAc'), risk score with collisions removed and junctions added ('RickJunc'), risk score with collisions removed and junctions added and treatments added ('RiskFeat') and the number of different treatments ('feat') – night time northbound data**

| | | Speed | Risk | RisknoAc | RiskJunc | RiskFeat | Feat |
|---|---|---|---|---|---|---|---|
| Speed | Pearson Correlation | 1 | -.593(**) | -.599(**) | -.600(**) | -.638(**) | -.576(**) |
| | Sig. (1-tailed) | | .001 | .001 | .001 | .000 | .001 |
| | N | 25 | 25 | 25 | 25 | 25 | 25 |
| Risk | Pearson Correlation | | 1 | .893(**) | .829(**) | .793(**) | .633(**) |
| | Sig. (1-tailed) | | | .000 | .000 | .000 | .000 |
| | N | | 25 | 25 | 25 | 25 | 25 |
| RisknoAc | Pearson Correlation | | | 1 | .922(**) | .835(**) | .620(**) |
| | Sig. (1-tailed) | | | | .000 | .000 | .000 |
| | N | | | 25 | 25 | 25 | 25 |
| RiskJunc | Pearson Correlation | | | | 1 | .921(**) | .700(**) |
| | Sig. (1-tailed) | | | | | .000 | .000 |
| | N | | | | 25 | 25 | 25 |
| RiskFeat | Pearson Correlation | | | | | 1 | .923(**) |
| | Sig. (1-tailed) | | | | | | .000 |
| | N | | | | | 25 | 25 |
| Feat | Pearson Correlation | | | | | | 1 |
| | Sig. (1-tailed) | | | | | | |
| | N | | | | | | 25 |

** Correlation is significant at the 0.01 level (1-tailed).
* Correlation is significant at the 0.05 level (1-tailed).

**Table C-6: Correlations (Pearson's r) between speed, risk score ('Risk'), risk score with collisions removed ('RisknoAc'), risk score with collisions removed and junctions added ('RickJunc'), risk score with collisions removed and junctions added and treatments added ('RiskFeat') and the number of different treatments ('feat') – night time southbound data**

| | | Speed | Risk | RisknoAc | RiskJunc | RiskFeat | Feat |
|---|---|---|---|---|---|---|---|
| Speed | Pearson Correlation | 1 | -.464(**) | -.591(**) | -.558(**) | -.711(**) | -.651(**) |
| | Sig. (1-tailed) | | .010 | .001 | .002 | .000 | .000 |
| | N | 25 | 25 | 25 | 25 | 25 | 25 |
| Risk | Pearson Correlation | | 1 | .839(**) | .768(**) | .677(**) | .403(*) |
| | Sig. (1-tailed) | | | .000 | .000 | .000 | .023 |
| | N | | 25 | 25 | 25 | 25 | 25 |
| RisknoAc | Pearson Correlation | | | 1 | .908(**) | .758(**) | .405(*) |
| | Sig. (1-tailed) | | | | .000 | .000 | .022 |
| | N | | | 25 | 25 | 25 | 25 |
| RiskJunc | Pearson Correlation | | | | 1 | .838(**) | .453(*) |
| | Sig. (1-tailed) | | | | | .000 | .012 |
| | N | | | | 25 | 25 | 25 |
| RiskFeat | Pearson Correlation | | | | | 1 | .866(**) |
| | Sig. (1-tailed) | | | | | | .000 |
| | N | | | | | 25 | 25 |
| Feat | Pearson Correlation | | | | | | 1 |
| | Sig. (1-tailed) | | | | | | |
| | N | | | | | | 25 |

** Correlation is significant at the 0.01 level (1-tailed).
* Correlation is significant at the 0.05 level (1-tailed).

**Table C-7: Partial correlations between speed and risk score ('Risk') when the effect of existing treatments ('Feat') is controlled – daytime northbound data**

| Control Variables | | | Speed | Risk |
|---|---|---|---|---|
| Feat | Speed | Correlation | 1.000 | -.458 |
| | | Significance (1-tailed) | . | .012 |
| | | df | 0 | 22 |
| | Risk | Correlation | | 1.000 |
| | | Significance (1-tailed) | | . |
| | | df | | 0 |

**Table C-8: Partial correlations between speed and risk score ('Risk') and risk score with collisions removed (RisknoAc') when the effect of existing treatments ('Feat') is controlled – daytime southbound data**

| Control Variables | | | Speed | Risk | RisknoAc |
|---|---|---|---|---|---|
| Feat | Speed | Correlation | 1.000 | -.216 | -.516 |
| | | Significance (1-tailed) | . | .156 | .005 |
| | | df | 0 | 22 | 22 |
| | Risk | Correlation | | 1.000 | .808 |
| | | Significance (1-tailed) | | . | .000 |
| | | df | | 0 | 22 |
| | RisknoAc | Correlation | | | 1.000 |
| | | Significance (1-tailed) | | | . |
| | | df | | | 0 |

**Table C-9: Partial correlations between speed and risk score ('Risk') when the effect of existing treatments ('Feat') is controlled – night time northbound data**

| Control Variables | | | Speed | Risk |
|---|---|---|---|---|
| Feat | Speed | Correlation | 1.000 | -.361 |
| | | Significance (1-tailed) | . | .042 |
| | | df | 0 | 22 |
| | Risk | Correlation | -.361 | 1.000 |
| | | Significance (1-tailed) | .042 | . |
| | | df | 22 | 0 |

**Table C-10: Partial correlations between speed and risk score ('Risk') and risk score with collisions removed (RisknoAc') when the effect of existing treatments ('Feat') is controlled – night time southbound data**

| Control Variables | | | Speed | Risk | RisknoAc |
|---|---|---|---|---|---|
| Feat | Speed | Correlation | 1.000 | -.291 | -.472 |
| | | Significance (1-tailed) | . | .084 | .010 |
| | | df | 0 | 22 | 22 |
| | Risk | Correlation | -.291 | 1.000 | .808 |
| | | Significance (1-tailed) | .084 | . | .000 |
| | | df | 22 | 0 | 22 |
| | RisknoAc | Correlation | -.472 | .808 | 1.000 |
| | | Significance (1-tailed) | .010 | .000 | . |
| | | df | 22 | 22 | 0 |

# Appendix D Additional details relating to questionnaire study to examine perceptions of signing and marking hierarchy

This section is designed to supplement Section 4 with additional detail on the methodology, analysis, and results. The stimuli used, along with the questionnaire, are available from the first author of this report. For illustration, the front page of the questionnaire (that shows an example picture with instructions to the participant, and questions answered for each picture rated) is shown in Section D.4.

## D.1 Design

The strict design is a 6x6 within-participants design. All participants viewed all levels of the treatment hierarchy. The pseudo-random order used for each individual participant was based on an initial completely random order of the 36 experimental pictures, and the nine 'distracter' pictures. This initial random order (a different one for each participant) was achieved using the 'RAND' function in Microsoft Excel (Office 2007 edition), and then sorting the order of picture stimuli by these random values. Then the order was changed manually (for each participant) to ensure that no participant saw a picture of a given bend immediately after another picture of the same bend. For example, it was not possible to see bend 'd1' (bend 'd', mocked up with treatment level '1') immediately after 'd2', 'd3', 'd4', 'd5', or 'd6'.

## D.2 Analysis

The analysis was a two-way (6x6) mixed ANOVA, with the two independent variables as listed in Section 4.1.2. The analysis used F-ratios with the Huynh-Feldt correction for Sphericity (see Huynh & Feldt, 1976).

## D.3 Results

The analysis showed that the main effects of bend and treatment level were both statistically significant, $F(4.14, 115.90)=11.18$, $p<0.001$ and $F(2.43, 68.15)=31.00$, $p<0.001$ respectively. The bend x treatment level interaction was non-significant, $F(14.09, 394.63)=1.58$, $p=0.08$.

## D.4 Front page of questionnaire

**Questionnaire**
You will be shown a series of pictures of single carriageway rural roads. Under each picture there will be a series of questions asking you about your own driving in the situation depicted in the photo. You are to imagine that you are driving along the road depicted, and answer the questions with respect to the exact point on the road shown in the photo – in other words if this was your exact view of the road ahead from your car. An example of this is given below with some example answers. There are no 'right' or 'wrong' answers – we want you to answer honestly with respect to your own driving (in your usual car), and with respect to the photo shown:

**At this point on this road:**

What speed would you normally be doing?
___________MPH

How difficult would you find it to drive at this speed?
Extremely easy Extremely difficult

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|

How risky would you find it to drive at this speed?
Not at all risky Extremely risky

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|

What speed would you feel is the fastest you could go here that would put you right at the edge of your safety margin?
___________MPH

How many times would you lose control of your vehicle if you drove at this speed 100 times?
___________times.

a/TRL/A377/1

# Appendix E **Illustrations of forward visibility and road-holding using the Devon data**

## E.1 Forward visibility

Any estimate of forward visibility using SCANNER data suffers from one major limitation – a SCANNER survey does not provide information about the width of any footway or verge over which a sight line could pass. In theory such information could be included within UKPMS but, in practice, few authorities are likely to have comprehensive information on footway and verge widths that could be used in an analysis. Therefore any estimate of forward visibility has to be made with an assumption about the effect of features at the edge of the carriageway; assuming, in effect, a standard verge width.

One approach would be to use the GPS data to build a three dimensional geometric model of the road, and then use a trigonometric analysis to estimate the forward visibility every 10m along the road. Such an analysis would combine both horizontal and vertical alignment. Although this is computationally straightforward, it was beyond the resources available at this stage.

An alternative, simpler, approach is to use the curvature data directly. This approach has been adopted in order to illustrate the potential of SCANNER data as a source of information about forward visibility. The forward visibility distance has been estimated every 10m along the road, in each direction, from simplistic assumptions about the position of the driver's eye, the position of the most likely obstructions (a pedestrian or stationary vehicle in the carriageway), a standard verge width (to a solid obstacle like a Devon hedge) and the curvature of the road. This estimate is not necessarily a realistic value, and is unlikely to be the exact value in many cases, but it is a consistent value along the length of the A377.

Separately, the safe stopping distance has been estimated for a range of speeds, allowing for reaction time and braking time at somewhat less than the full emergency rate, to allow for a driver not concentrating fully on the task, and a vehicle and road surface in less than perfect condition. Again, these estimates are not necessarily realistic values, and may not be the most appropriate values, but they do provide a consistent basis.

Taking the estimated forward visibility at any point as the safe stopping distance, a safe stopping speed can be estimated every 10m along the road. This can be illustrated on a series of bends south of Lapford Cross.

Figure E-1 shows the SCANNER measured OSGR co-ordinates from two separate surveys (one in each direction) over a length of about 2.5km of the A377, immediately south of Lapford Cross. At this scale the data points seem co-incident.

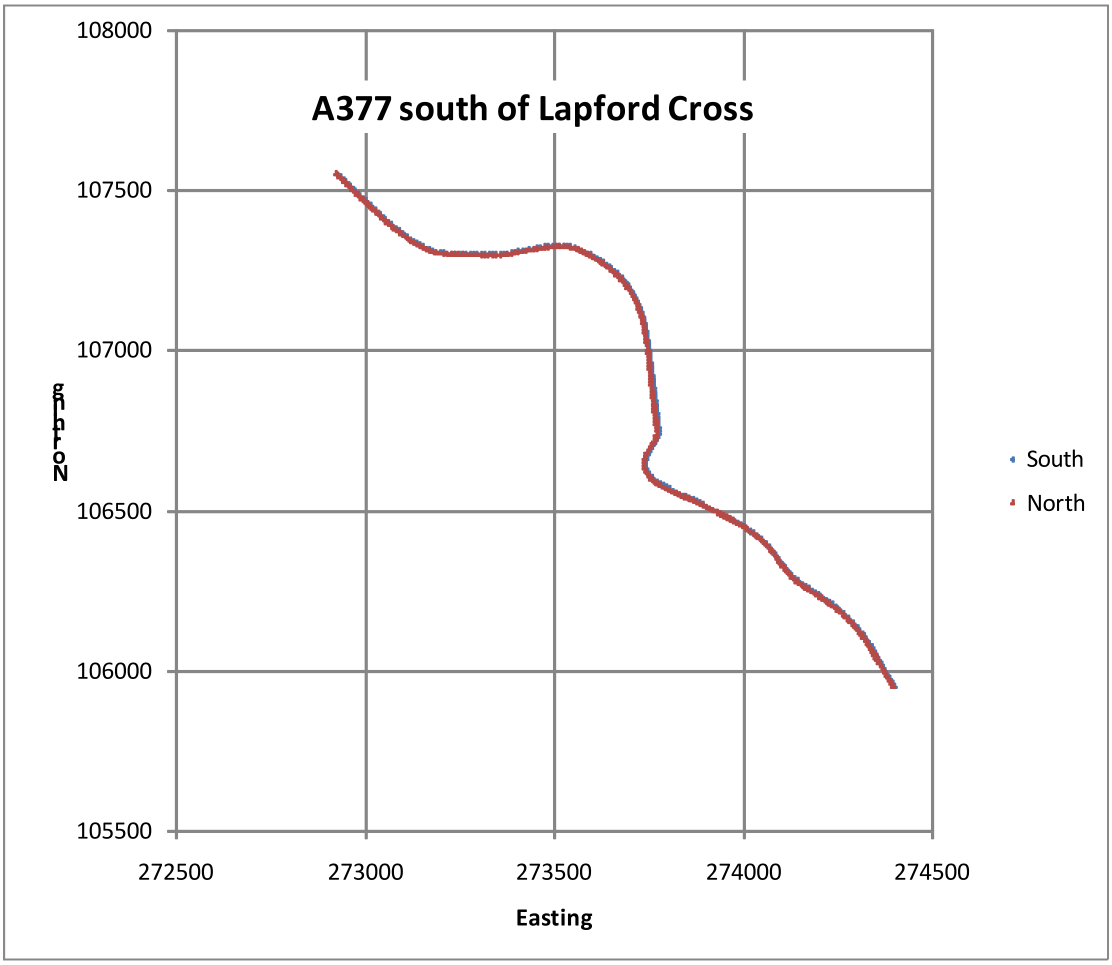



**Figure E-1: SCANNER OSGR co-ordinates, A377, south of Lapford Cross**

Figure E-2 shows the average curvature, over 5 subsections (the 50m rolling average value) for the southbound and northbound directions.

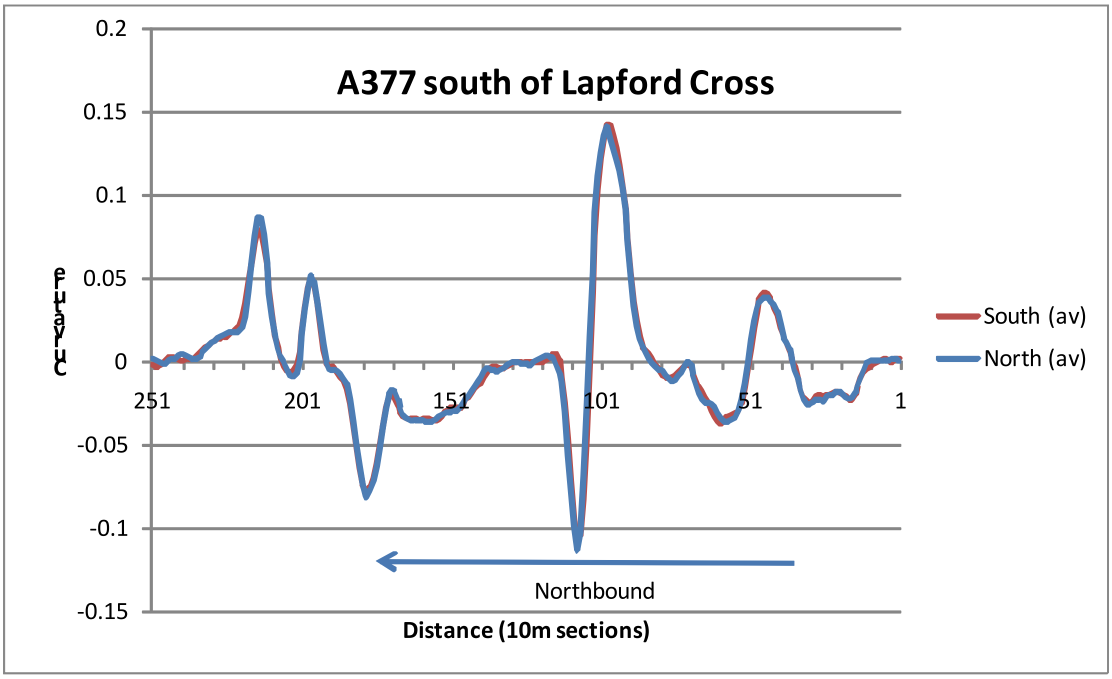



**Figure E-2: Comparing averaged SCANNER curvature, northbound and southbound**

The “stopping speed” estimated from the curvature data is shown in Figure E-3 for a vehicle travelling north. A maximum value of 116 km/h is used, simply for the purposes of calculation and illustration. The SCANNER survey vehicle speed is shown, for comparison. This clearly shows that the survey vehicle does slow as it approaches and traverses the bends. There is no significance that the “stopping speed” appears to be less than the survey vehicle speed, as the “stopping speed” is simply a calculated value, based on very approximate assumptions about forward visibility and is only used to illustrate the principle.

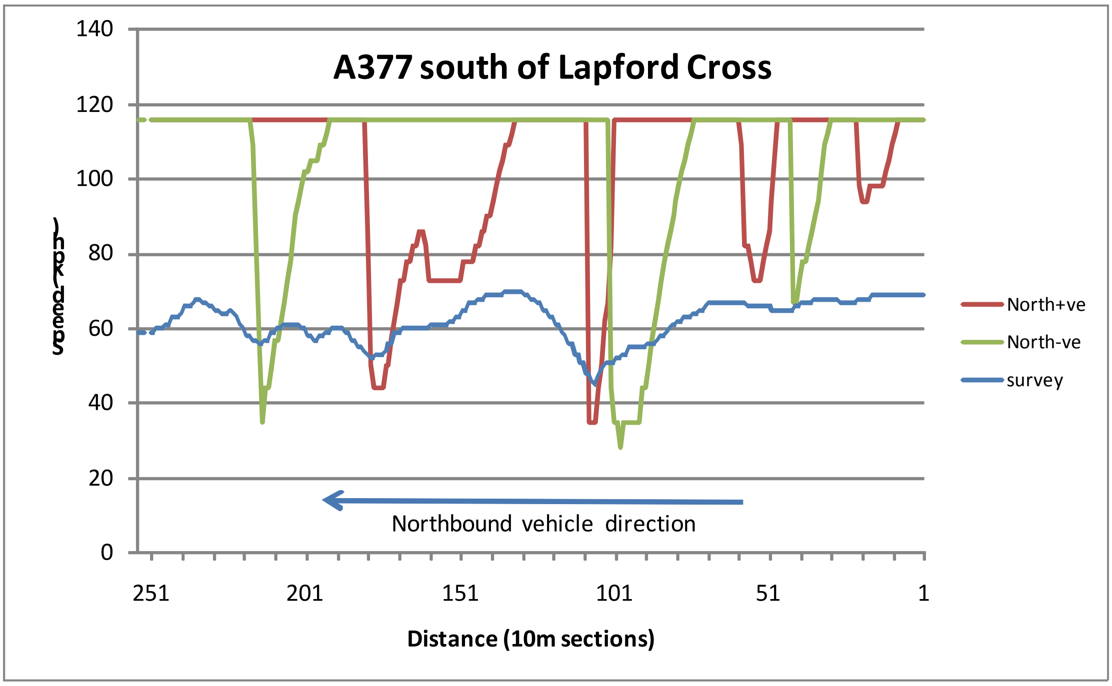



Figure E-3: Comparing visibility based estimated “stopping speed” with survey vehicle speed northbound (For a vehicle travelling northbound, a positive bend is to the left - red - and a negative bend is to the right - green.

The “stopping speed” estimated from the curvature data is shown in Figure E-4 for a vehicle travelling south.

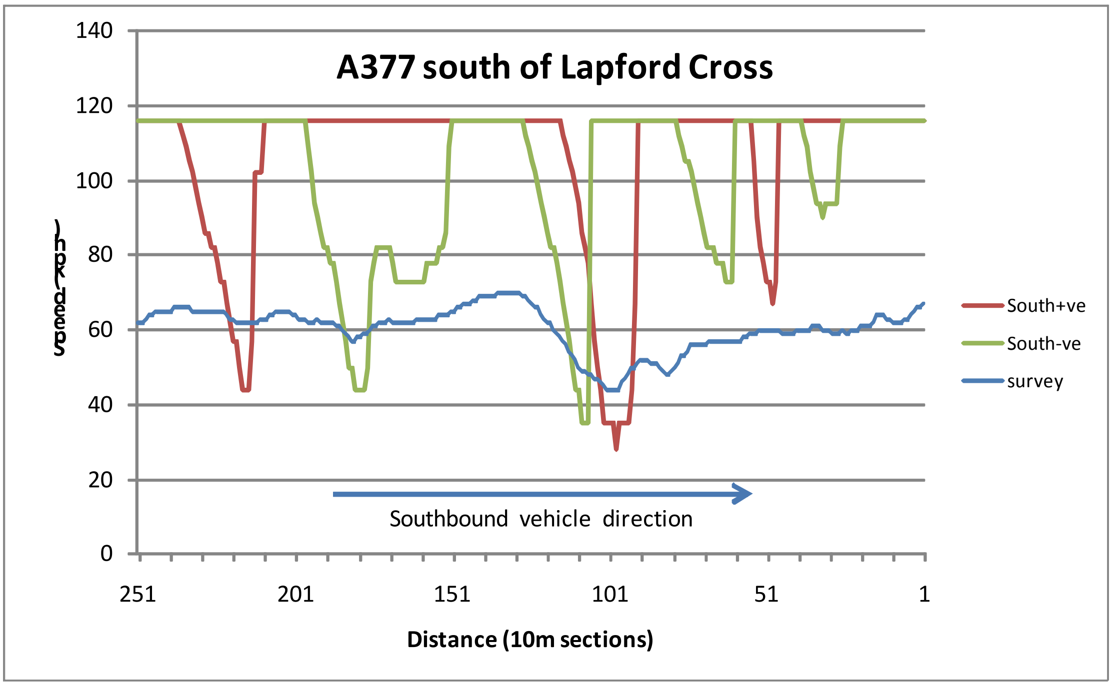



**Figure E-4: Comparing visibility based estimated "stopping speed" with survey vehicle speed southbound (For a vehicle travelling southbound, a positive bend is to the left – red - and a negative bend is to the right - green).**

One alternative approach to rating the severity of bends would be to use an estimated safe stopping speed, rather than simply the minimum radius of curvature.

This concept can be investigated in more detail on the sharp double bend at Bury Cross, at the middle of the section south of Lapford Cross. This is bend 24 of the driver test study bends.

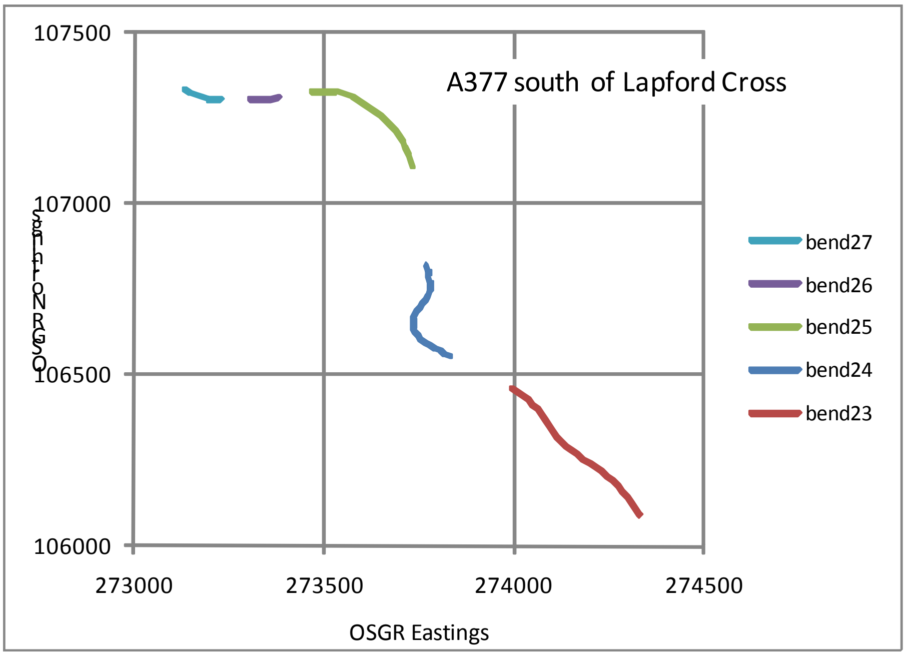



**Figure E-5: Location of driver perception test bends south of Lapford Cross**


**Figure E-6: Approaching test bend 24, northbound, south of Lapford Cross**

The SCANNER survey OSGR co-ordinates (from a very high specification system) in Figure E-7 may be compared with the driver perception test GPS co-ordinates (from the lower specification system used on the test car) in Figure E-8.

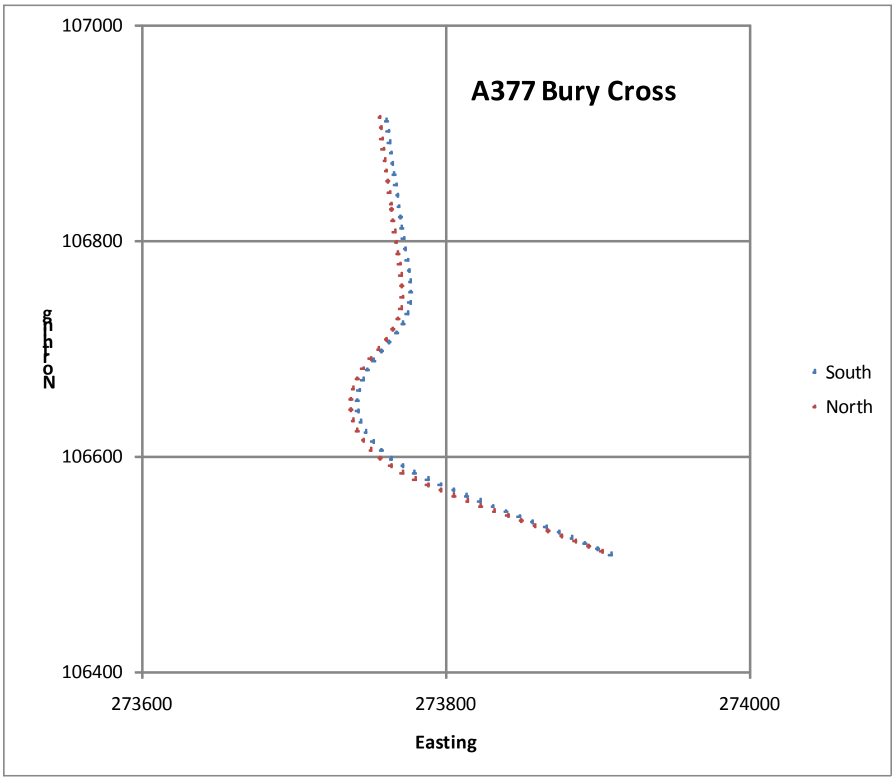



**Figure E-7: SCANNER OSGR co-ordinates, test bend 24, south of Lapford Cross**

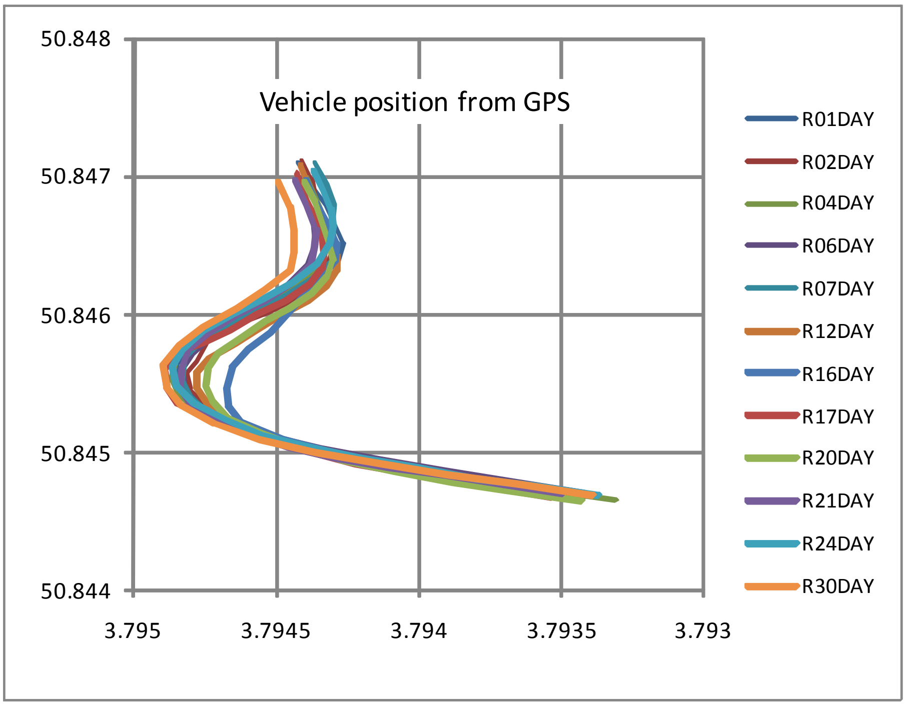



**Figure E-8: Driver perception test GPS co-ordinates, test bend 24, south of Lapford Cross**

The SCANNER survey vehicle speed and the estimated "stopping speed" may be compared with the test drive data in both the northbound and southbound directions, as shown below in Figures E-9 and E-10, and Figures E-11 and E-12.

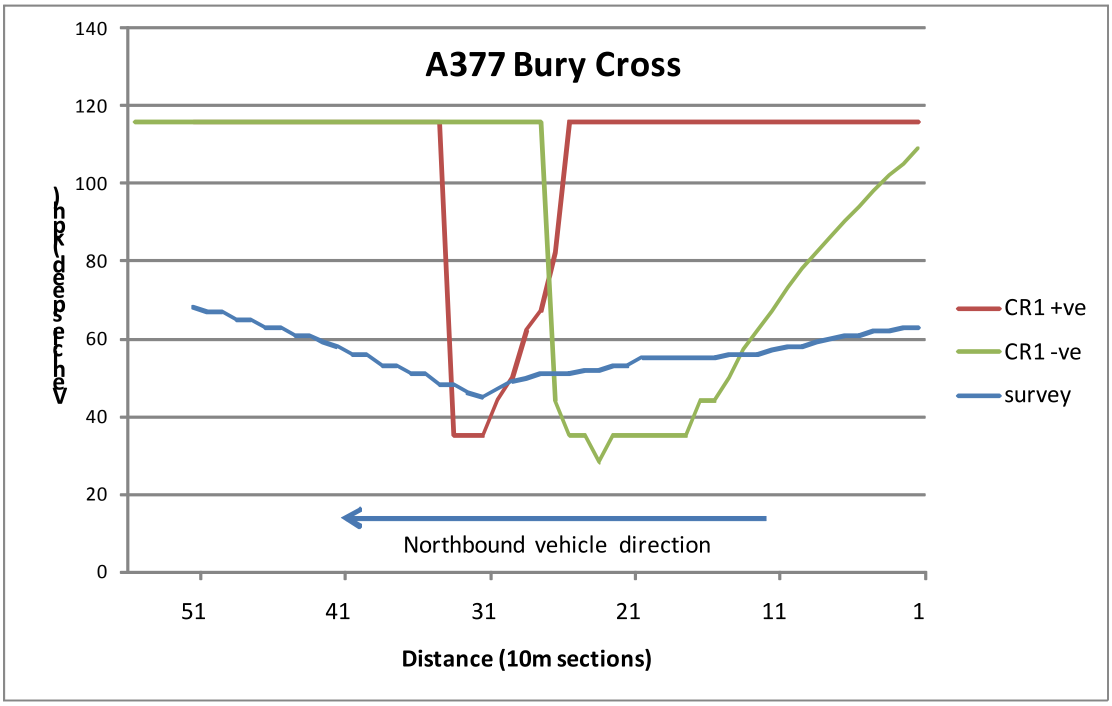



**Figure E-9: Comparing visibility based estimated "stopping speed" with survey vehicle speed northbound, test bend 24**

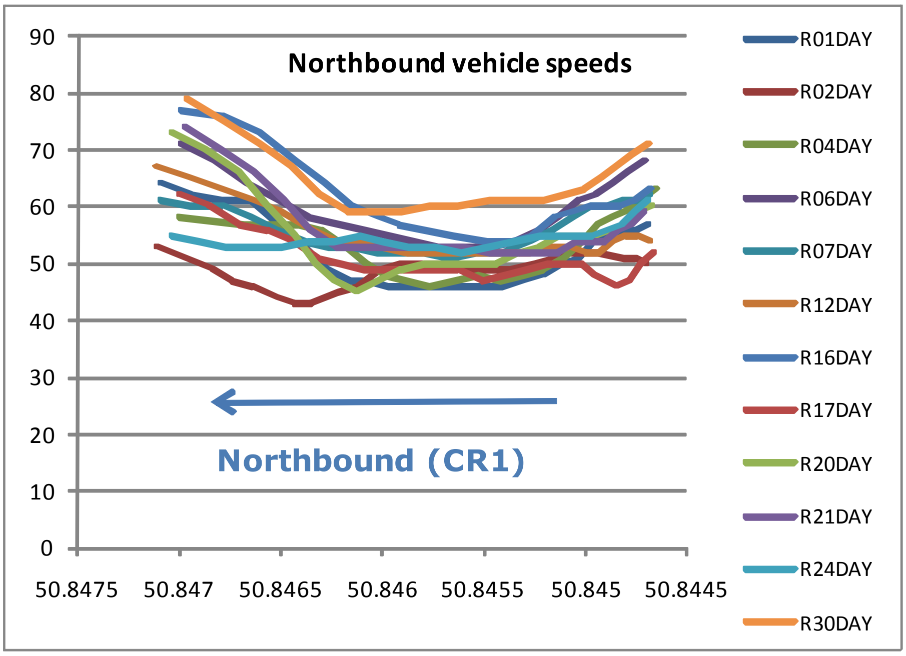



**Figure E-10: Driver test vehicle speeds northbound, test bend 24**

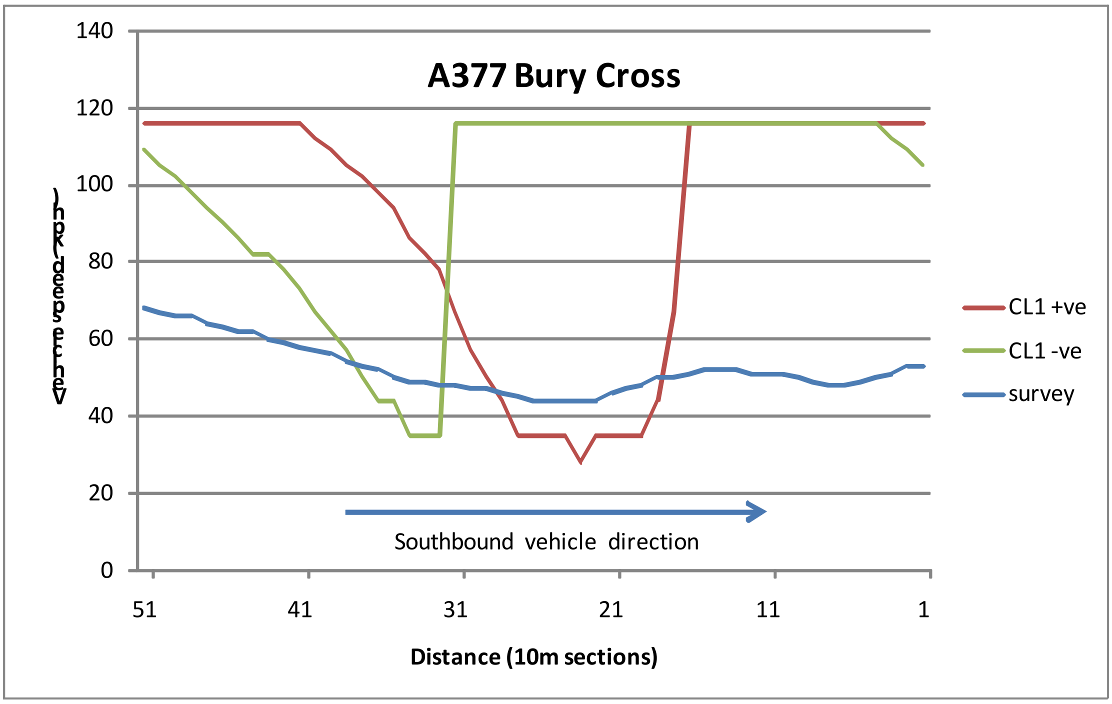



**Figure E-11: Comparing visibility based estimated "stopping speed" with survey vehicle speed southbound, test bend 24**

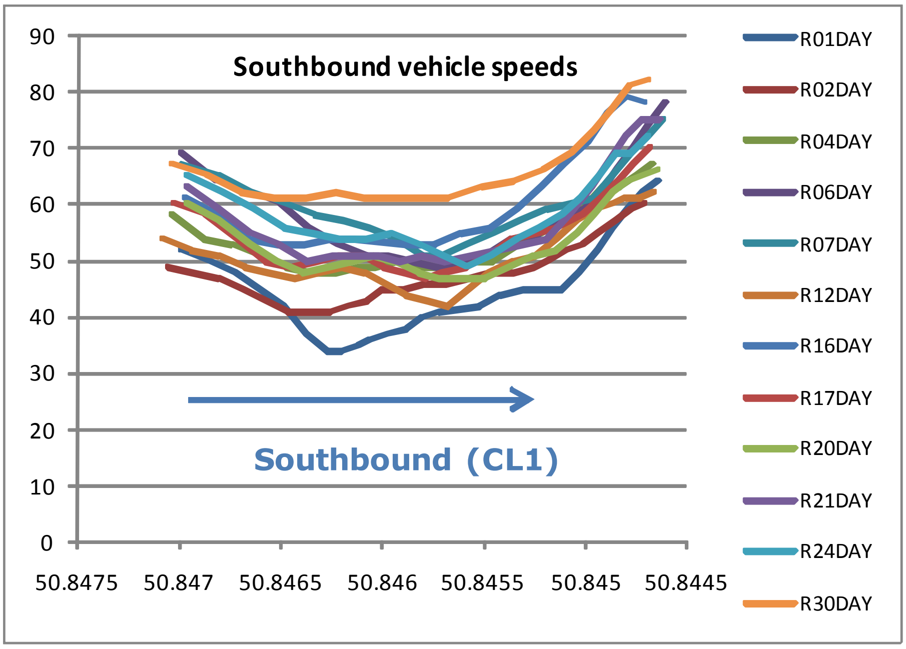



**Figure E-12: Driver test vehicle speeds southbound, test bend 24**

This illustrates the potential of SCANNER survey data to estimate forward visibility and hence rate the bend severity in terms of a safe stopping distance (rather than simply the minimum radius of curvature).

However there were not sufficient resources to develop the approach further within this project.

## E.2 Road holding and driver comfort

SCANNER data can also be analysed to investigate the effect of road geometry on road holding and driver comfort. There are two main forces acting on a vehicle, its contents and occupants as it rounds a bend, gravity and a centripetal force (see equation (1) in Section B.3) The gravity force is independent of speed and the tightness of the bend, but is modified by any superelevation. The centripetal force depends on both speed and the tightness of the bend, but not on the superelevation.

For a vehicle to round the bend without sliding, the sideways friction on the tyres, plus any contribution from the superelevation, must be greater than the centripetal force required.

In practice, as described in Section B.3) for passenger cars in good weather conditions, the sideways force on the tyre is hardly ever the limiting factor provided the road surface is in good condition and free from contamination, because the tyres on modern vehicles are able to provide a high sideways force, and hence a large centripetal acceleration, so that driver discomfort is more often the limiting factor. This may not be true for two wheeled vehicles, where the rider may choose to tilt the vehicle and generate very high demands for sideways force on the tyres, or for heavy goods vehicles.

It is possible to calculate a "comfortable handling" speed from the radius of curvature every 10m along the road, making allowance for any contribution from cross fall, which may be either positive or negative, and assuming a comfortable coefficient of friction between the tyre and road (0.15 used for these calculations).

This may be illustrated on the same series of bends, south of Lapford Cross.

Figure E-1 shows the SCANNER measured OSGR co-ordinates from two separate surveys (one in each direction) over a length of about 2.5km of the A377, immediately south of Lapford Cross.

Figure E-2 shows the average curvature, over 5 subsections (the 50m moving average value) for the southbound and northbound directions.

The "comfortable handling" speed calculated from the radius of curvature and cross fall data is shown in Figure E-12 for a vehicle travelling north. A maximum value of 100 km/h is used, simply for the purposes of calculation and illustration. The SCANNER survey vehicle speed is shown, for comparison. This clearly shows that the survey vehicle does slow at places where the "comfortable handling" speed falls below 100 km/h. There is no significance that the "comfortable handling" speed appears to be less than the survey vehicle speed, as the "comfortable handling" speed is simply a calculated value, based on approximate assumptions about what centripetal acceleration would be comfortable, not what would be a "road holding" limit speed, and is used to illustrate the principle. (A "road holding" limit speed would also depend on the type of vehicle).

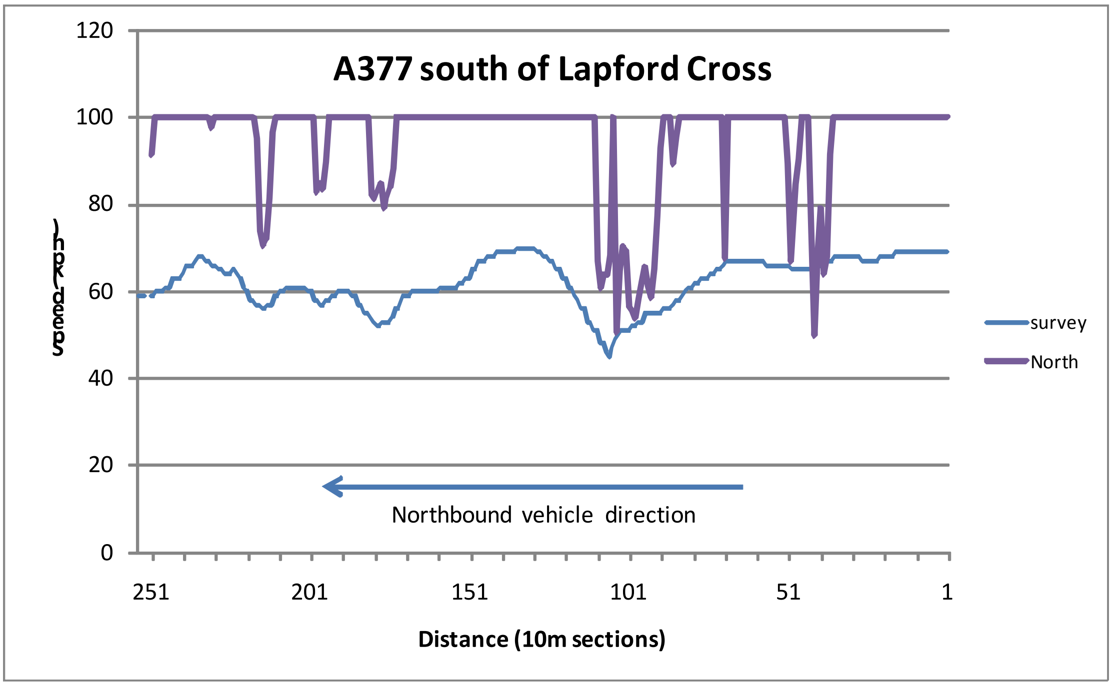



**Figure E-12: Comparing estimated "comfortable handling" speed with survey vehicle speed northbound**

The "comfortable handling" speed calculated from the radius of curvature and cross fall data is shown in Figure E-13 for a vehicle travelling south. It appears that there are some places where the "comfortable handling" speed falls well below 100km/h, and yet seems to have little effect on the survey vehicle speed.

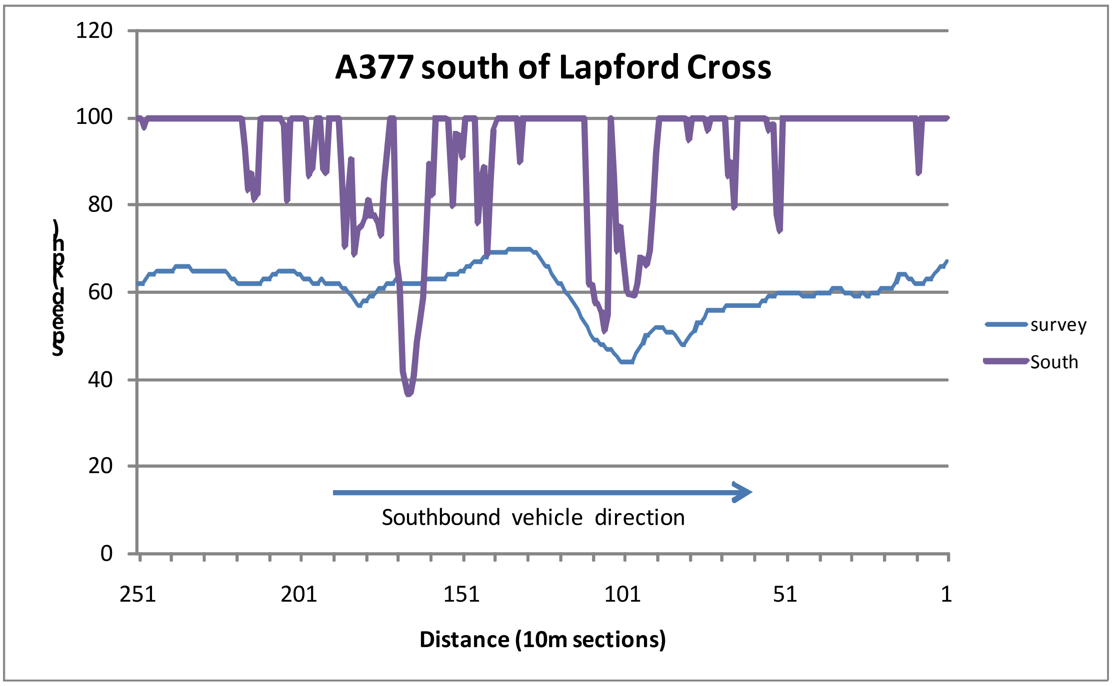



**Figure E-13: Comparing estimated "comfortable handling" speed with survey vehicle speed southbound**

One alternative approach to rating the effect of cross fall on the severity of bends would be to use an estimated "comfortable handling" speed. However there were not sufficient resources to develop the approach further within this project.

## E.3 Comparing visibility and comfortable handling speeds

It is possible to compare the estimated "stopping speed" based on forward visibility and the estimated "comfortable handling" speed. Figure E-14 shows the comparison, northbound, and Figure E-15 shows the comparison, southbound on the same 2.5 km length of the A377, south of Lapford Cross.

The estimated "stopping speed" is limited to 116 km/h, and the estimated "comfortable handling" speed is limited to 100 km/h, simply to separate the maximum values. These are both arbitrary values. The places of interest are those where considerations of either forward visibility or comfortable handling reduce the appropriate speed below the local speed limit.

From the perspective of this study, the more interesting places are those where drivers' perception leads them to adopt a speed that is significantly greater than that from which they could safely stop, in an unanticipated circumstance, or that is significantly greater than a safe road holding speed in an unanticipated circumstance.

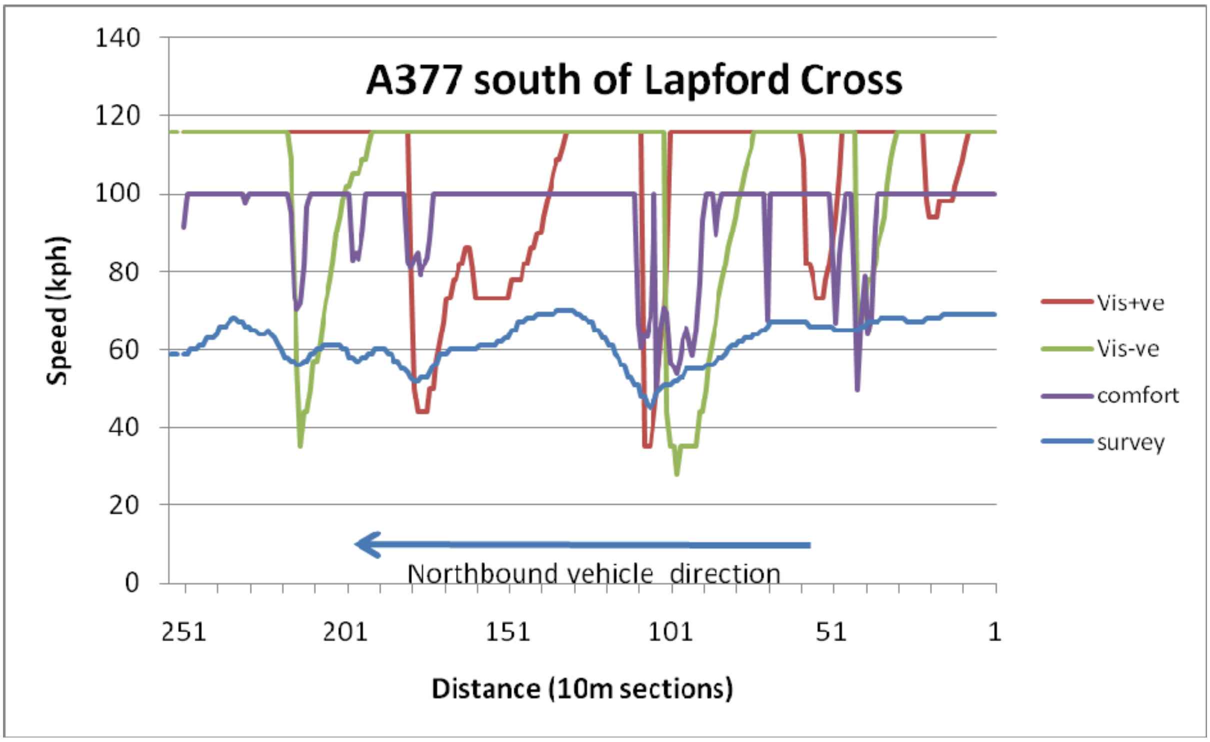



**Figure E-14: Visibility and comfortable handling speeds northbound**

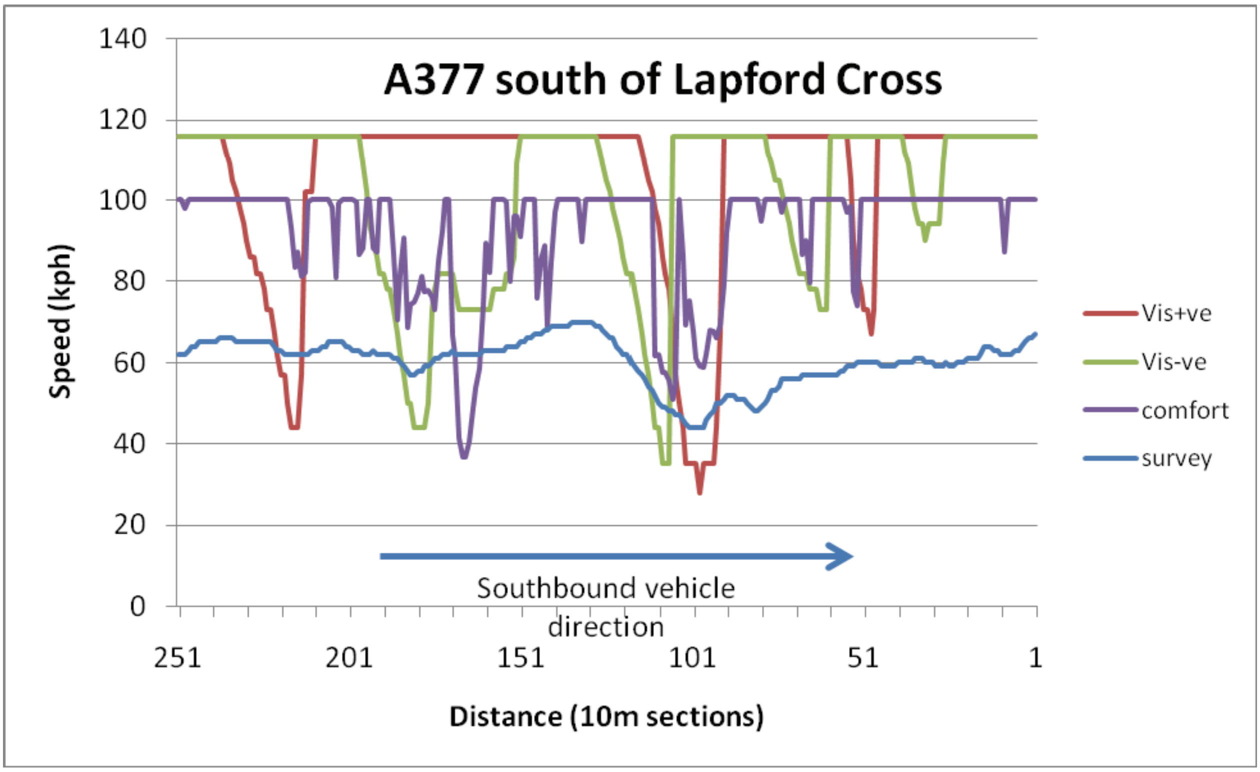



**Figure E-15: Visibility and comfortable handling speeds southbound**

Differences between drivers' comfortable handling speed and forward visibility safe speed might be an even more sophisticated approach to identifying those places where drivers who are familiar with the road may (subconsciously) be driving "faster" than a safe stopping speed, and are therefore travelling at risk, in the event of an unanticipated occurrence.

# Bend treatments on the A377 between Cowley and Bishops Tawton – final report

An approach to making bend treatments (signing and marking) consistent on a rural route was evaluated using behavioural data. Risk scores were assigned to bends on the A377 in Devon, on the basis of geometric and cross-fall information from the SCANNER road survey system, and collision data. Bends with tighter radii, low cross-fall values, and more collisions during a defined period, were assigned higher risk scores. A sample of drivers who regularly use the A377 drove a section of the route with 25 bends of varying risk score. The drives were managed by an accompanying driving instructor who attempted to ensure that drivers were free to choose their own speeds throughout. Mean speeds driven through the bends were negatively correlated (moderately to strongly) with risk score, suggesting that the risk scores possessed validity with respect to real driving behaviour (i.e. drivers moderated their speed in a way that suggests they are sensitive to the risk/difficulty of bends, as represented by the risk score). A short questionnaire study elicited speed estimates from drivers in response to picture mock-ups showing different levels of treatments on bends, corresponding to a six-level hierarchy of signing and marking. This showed that drivers lowered their speed estimates as the level of treatment depicted increased. The findings are discussed in relation to the use of the general approach being taken on the A377, and how it might apply to assigning risk, and treatment options, on other rural roads.

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