Traffic signal controlled pedestrian crossings on high-speed roads

Version: Issue 1

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Client: Traffic Management Division, Department for Transport
(Mr. S. Phull)

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Executive summary

The objective of project UG227B for the Department of Transport was to review the guidelines for installing traffic signal controlled crossings on high-speed roads. Current Department for Transport publications offer different advice on the maximum 85th percentile (the value which 85% are below) speed above which it is considered unwise to install signal controlled stand-alone (sometimes described as mid-block or mid-link) pedestrian crossings, and signal control of junctions with or without pedestrian facilities. This advice ranges from 50 mph (80 km/h) for stand-alone crossings to 65 mph (105 km/h) for junctions. For stand-alone pedestrian crossings, with vehicles approaching with an 85th percentile speed above 50 mph (80 km/h), ‘serious consideration’ of ‘speed reduction measures’ is recommended ‘prior’ to installation. For signal controlled junctions, installation is ‘not recommended’ where approach speeds exceed 65 mph (105 km/h).

Presently, providing a stand-alone crossing facility on a road with an 85th percentile speed greater than 50 mph (80 km/h) could involve the construction of a bridge or underpass, neither of which may offer the most appropriate pedestrian crossing facility. In contrast, the provision of a pedestrian phase at a signal controlled junction could be undertaken on roads with an 85th percentile speed of up to 65 mph (105 km/h).

This project examined both ‘real’ and ‘perceived’ differences and difficulties resulting from the provision of stand-alone signal controlled crossings and signal controlled junctions with pedestrian facilities. The project had three elements:

- Investigation of users’ behaviour at a selection of sites, stand-alone crossings and signal controlled junctions with pedestrian facilities
- A driving simulator study of the behaviour of drivers
- An investigation of factors affecting the safety record at a selection of sites

The investigation of users’ behaviour at the selected sites concentrated on the behaviour of the pedestrians rather than the drivers. It is very difficult to determine drivers’ behaviour from outside a vehicle, but relatively easy in the TRL driving simulator. The simulator also offered the opportunity to present drivers with many difficult decisions as to whether to continue or to stop at the signals in a reasonably short “drive.” Therefore, the investigation of differences in drivers’ behaviour on the approach to the two types of crossings concentrated on the driving simulator results.

A definitive study of differences in the safety record of the two types of signal controlled crossings on high-speed roads would require far more resources than were available within this project. A study of accidents at the sites where pedestrians’ behaviour had been studied was undertaken. The aim was to investigate whether any guidance on special factors to be considered when designing and operating pedestrian crossings on high-speed roads could be given. The main conclusions were:

On-road study of pedestrian behaviour

The behaviour of cyclists crossing the road at the crossings and junctions was analysed as well as that of pedestrians using the crossings. No obviously unsafe behaviour was observed at any of the stand-alone crossings or junctions during the on-street study. There was no evidence that pedestrians and cyclists who crossed against the traffic signals chose to cross in different length gaps at junctions or at stand-alone crossings. Typically the gaps chosen meant that the person crossing had cleared the potential collision zone 6 seconds before a vehicle entered the zone. There was a slight indication of frustration due to the time waiting for an invitation to cross at the stand-alone crossing in Birmingham; pedestrians were seen to re-press the demand button, several times in some cases. The proportion crossing against the signals increased with average waiting time at both stand-alone crossings and junctions. The implication from the Nottingham sites, however, is that the probability of crossing against the signals is greater at a stand-alone crossing than at a junction with similar vehicle flows and waiting times.

Simulator study of drivers’ behaviour

Two roads were used in the simulator study of driver behaviour, a single carriageway and a dual carriageway. The experiment was designed to examine behaviour at speeds around the upper limit in
the guidance for stand-alone crossings and drivers did drive in the desired speed range. Average speeds on the approach to traffic signals (160m before the stopline) were 88 km/h on the single carriageway and 93 km/h on the dual carriageway. Results from this part of the study show a difference in the behaviour of drivers approaching traffic signal controlled junctions and signal controlled stand-alone crossings on high-speed roads. All the measures of behaviour showed drivers being more cautious at the junctions than the mid-block crossings:

- Approach speeds were lower (85th percentile 4km/h lower from 250m before the stopline) at the junctions
- Drivers were more likely to stop when the signals changed from green on their approach to a junction, particularly when the change occurred close (40 to 80m) to the stopline
- Drivers were more likely to cross the stopline in the last second of amber or to red-run at stand-alone crossings than junctions
- Drivers used more controlled braking when the signals changed from green to amber at over 60m before the stopline on the approach to a junction than on the approach to a stand-alone crossing. When the signals changed at closer distances they were willing to accept higher deceleration rates to stop at junctions than at stand-alone crossings.

Results from the questionnaire filled in after the simulator drives confirmed the suitability of the simulator for the trial and that the participants tend to approach signal controlled junctions with more caution than stand-alone signal controlled pedestrian crossings.

**Accident study**

The accident records at each of the sites studied in the first phase of the project were analysed for factors that might be particularly relevant at high-speed signal controlled sites. It was not possible to draw any firm conclusions as the number of accidents was very small. It is possible that masking of on-coming vehicles by stopped vehicles is more common at high-speed sites than lower speed ones, because of the combination of multiple lanes and the possibility of high-speeds in unobstructed lanes. Overall there was no clear evidence of a difference in pedestrian casualty risk at stand-alone crossings and signal controlled junctions. However, the severity ratio, particularly for the pedestrian junction casualties, did reinforce the potential danger to pedestrians from faster moving vehicles.

**Overall**

There is strong evidence from the simulator study that drivers approach traffic signalled junctions more cautiously and are more likely to stop when the signals change against them than at stand-alone crossings.

The on-road study of pedestrians showed similar behaviour at the two types of installation, except an indication of a greater propensity to cross against the signals at stand-alone crossings than at junctions. The study emphasised the need to keep pedestrian waiting times as short as possible to minimise the number of pedestrians who cross against the signals. Double-cycling UTC controlled crossings significantly reduces pedestrians' waiting time. At the majority of the sites studied the method of operation resulted in longer delays to pedestrians at the stand-alone crossings than at junctions for those who waited for the main road vehicular traffic to be stopped. Longer waits result in increasing numbers of pedestrians crossing against the signals, providing further evidence of the need for more cautious guidelines on the installation of stand-alone crossings than signal controlled junctions.

The accident study did not identify any factors that affected accidents differently at stand-alone crossings and junctions. It did emphasise the danger to pedestrians from fast moving vehicles and the dangers of pedestrians’ view of approaching vehicles being masked by stationary vehicles.

It is considered that the results of this study, particularly the simulator trial, justifies the provision of more cautious guidelines for the installation of stand-alone, signal controlled crossings than for signal controlled junctions on high-speed roads. A much larger study would be required to thoroughly validate the exact details of the guidelines, but there is no evidence from this study of any problems with the current guidance on where to use signal controlled crossings. The operation of crossings should consider the strong desire of pedestrians for short waiting times.
1 Introduction

The objective of project UG227B for the Department of Transport was to review the guidelines for installing traffic signal controlled crossings on high-speed roads. Current Department for Transport publications offer different advice on the maximum 85th percentile speed above which it is considered unwise to install signal controlled stand-alone (sometimes described as mid-block or mid-link) pedestrian crossings, and signal control of junctions with or without pedestrian facilities. This advice ranges from 50 mph (80 km/h) for stand-alone crossings to 65 mph (105 km/h) for junctions. For stand-alone pedestrian crossings, with vehicles approaching with an 85th percentile speed above 50 mph (80 km/h), ‘serious consideration’ of ‘speed reduction measures’ is recommended ‘prior’ to installation. For signal controlled junctions, installation is ‘not recommended’ where approach speeds exceed 65 mph (105 km/h).

Presently, providing a stand-alone crossing facility on a road with an 85th percentile speed greater than 50 mph (80 km/h) could involve the construction of a bridge or underpass, neither of which may offer the most appropriate pedestrian crossing facility. In contrast, the provision of a pedestrian phase at a signal controlled junction could be undertaken on roads with an 85th percentile speed of up to 65 mph (105 km/h).

This problem is likely to become more acute given the current emphasis on providing enhanced facilities for pedestrians, cyclists and equestrians.

This project examined both ‘real’ and ‘perceived’ differences and difficulties resulting from the provision of stand-alone signal controlled crossings and signal controlled junctions with pedestrian facilities, on roads with 85th percentile speeds exceeding 50 and 65 mph (80 and 105 km/h) respectively.

The project had three elements:

- Investigation of users’ behaviour at a selection of sites, stand-alone crossings and signal controlled junctions with pedestrian facilities
- A driving simulator study of the behaviour of drivers
- An investigation of factors affecting the safety record at a selection of sites

The investigation of users’ behaviour at the selected sites concentrated on the behaviour of the pedestrians rather than the drivers. It is very difficult to determine drivers’ behaviour from outside a vehicle, but relatively easy in the TRL driving simulator. The simulator also offered the opportunity to present drivers with many difficult decisions as to whether to continue or to stop at the signals in a reasonably short “drive.” Therefore, the investigation of differences in drivers’ behaviour on the approach to the two types of crossings concentrated on the driving simulator results.

A definitive study of differences in the safety record of the two types of signal controlled crossings on high-speed roads would require far more resources than were available within this project. A study of accidents at the sites where pedestrians’ behaviour had been studied was undertaken. The aim was to investigate whether any guidance on special factors to be considered when designing and operating pedestrian crossings on high-speed roads could be given.

This report is the final report from the project and covers the results from all three phases.

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1 85th percentile is the value which 85% of the observations are below
2 Site selection for on-street investigations

Local authorities and the Highways Agency were contacted and asked to nominate suitable sites for the study. The desired characteristics were:

- Appreciable pedestrian flows
- Approach speeds of 45 mph or more

The project was to investigate the relevance of having different guidelines for stand-alone crossings and signal controlled junctions with pedestrian facilities. The guidance only diverges for approach speeds above 50 mph; therefore, the aim was to investigate sites with approach speeds close to or above 50 mph. It was unlikely, however, that authorities would have installed stand-alone crossings at sites where the speeds are above the guidelines. Hence, the request for sites with approach speeds of at least 45mph. It proved surprisingly hard to find suitable sites; authorities appear to have been reluctant to install crossing facilities on roads with approach speeds much in excess of 45 mph.

For some suggested sites, the local authority was able to provide speed survey information, at all others TRL staff conducted a survey in accordance with TA 22/81 as part of the assessment of the suitability of the site. When all the suggested sites had been assessed, 4 stand-alone crossings with reasonable numbers of pedestrians crossing the road were selected. In order to find sufficient suitable sites, however, the original speed criterion had to be relaxed to include sites where the 85th percentile approach speed was close to or above 40 mph, rather than 45 mph.

At the high speed sites under consideration, the number of pedestrians crossing fast approaches was fewer than had originally been thought desirable for the study. However, there was a junction close to each of the selected stand-alone crossings on the same road as the crossing. By selecting these junctions for study, it was possible to study pedestrians crossing effectively the same vehicular traffic at a junction and at a stand-alone crossing. The pedestrians crossing the road were likely to be different, and considerably fewer in number at some of the junctions, but the effect of the vehicular traffic should be similar to provide a good basis for comparing pedestrian behaviour at the two types of crossing.

The following sites were selected and are described below:

- A259 at Ferring in West Sussex
- A45, Coventry Road in Birmingham
- A52, Derby Road in Nottingham
- B4114 at Enderby in Leicestershire

In addition results of a previous study for the Highways Agency were available. The sites studied for the HA were:

- A50 at Uttoxeter, Staffordshire
- A43 at Towcester, Northamptonshire

2.1 Ferring

The first site selected was on the A259 at Ferring in West Sussex, which had been the subject of a speed reduction scheme (Pedler and Ekinsmyth 2002). The site is a T junction where vehicles exiting the side road have to turn left. In addition only buses are allowed to turn right into the side road. The layout means that the signals on the Eastbound carriageway are effectively a stand-alone crossing, but the signals on the Westbound carriageway control a junction, with pedestrian facilities. This installation includes an equestrian crossing, but the presence of the horse crossing was not expected to influence pedestrian behaviour. In practice it was found that few horse riders used the crossing and there was negligible interaction between horses and pedestrians. It was, however, noticeable that all
the (few) observed horse riders waited for a green signal before starting to cross. The site is shown in Figure 2-1 to Figure 2-2.

![Figure 2-1: Ferring pedestrian crossing on the Eastbound carriageway](image1)

![Figure 2-2: Ferring junction on the Westbound carriageway](image2)
Speed surveys had been undertaken as part of the speed reduction scheme. On the Eastbound carriageway the 85th percentile approach speed was between 50 and 55 mph. On the Westbound carriageway it was between 45 and 55 mph. That is the speed approaching the junction was less than that approaching what is effectively a stand-alone crossing.

2.2 Birmingham

Birmingham City Council suggested several sites, but the approach speeds were lower than ideal for the project. However, some were higher than most of the other sites suggested by authorities. It was decided to survey a crossing and a junction on the A45, Coventry Road. The junction was the junction of Coventry Road and Holder Road and the Pelican crossing was about 150 metres East of the junction, adjacent to Henry Close. The A45 is a wide “fast” road, but because of the volume of traffic throughout most of the day, the speeds are not very high. When the speeds were measured by a member of TRL staff, it was found that the speed of Westbound vehicles was slightly higher than that of Eastbound vehicles, particularly at the Pelican crossing and so it was decided to survey pedestrian behaviour on that carriageway. The measured 85th percentile speeds on the Westbound carriageway were:

- Approaching the Pelican crossing adjacent to Henry Close 43 mph
- Approaching the junction with Holder Road 40 mph

The two sites are shown in Figure 2-3 and Figure 2-4.
2.3 Nottingham

The A52 Derby Road in Nottingham between the A607 and A6464 is a dual-carriageway, mainly bus lane plus two general traffic lanes in each direction, with several signal controlled junctions and crossings. The road is subject to a 40 mph speed limit. As at Birmingham, the approach speeds were not as high as initially specified for surveys, but proved to be amongst the highest of those offered by local authorities. Speed surveys at several suggested sites in Nottinghamshire, including the junctions and crossings on the Derby Road, in Nottingham were undertaken by TRL. The sites with the highest approach speeds were on the A52 towards Nottingham at the Pelican crossing near Moor Lane and the junction with the B6006. At both these sites the 85th percentile approach speeds were 42 mph. The sites are shown in Figure 2-5 and Figure 2-6. The figures are still images captured from the analysis video.
Figure 2-5: Pedestrian crossing, A52 Nottingham near Moor Lane

Figure 2-6: Junction of A52 and B6006, Nottingham
2.4 Leicester

Several sites in Leicestershire were suggested by City Council officers and surveyed by TRL. The most suitable combination of pedestrian flows and approach speeds for a junction and stand-alone crossing on the same road were on the B4114, Enderby. The pedestrian crossing adjacent to Sainsbury’s had 85\textsuperscript{th} percentile approach speeds of 44 mph and much higher pedestrian flows than at any other of the Leicestershire sites. The signal controlled junction adjacent to the police station had a higher approach speed, 48 mph, but lower pedestrian flows. The two sites are shown in Figure 2-7 and Figure 2-8.

Figure 2-7: Leicester B4114, junction at police HQ

Figure 2-8: Leicester B4114, Toucan crossing by Sainsbury's
2.5 HA sites, Uttoxeter and Coventry

The Highways Agency had previously contracted TRL to study two new pedestrian crossings on high-speed roads. These were a crossing of the A50 at Uttoxeter and of the A43 at Towcester. The Towcester crossing included an equestrian facility. Both these crossings were close to roundabouts on major high-speed roads where most of the junctions are grade separated. No other sites on HA roads were thought to be suitable for this study. The crossing at Uttoxeter is shown in Figure 2-9, taken from the analysis video. The top two images are of vehicles approaching the roundabout, a wider view to show vehicles approaching and a close up of the crossing to show the pedestrians and signal aspects clearly. The bottom two images are equivalent views of vehicles leaving the roundabout. The Towcester crossing is shown in Figure 2-10.
Figure 2-10: Crossing of A43 at Towcester
3 On-street surveys

3.1 Method

Video recordings were used for the on-street surveys undertaken in this project for several reasons. Using video recording is a discrete way of collecting data. The aim was to record the normal behaviour of both pedestrians and drivers. The presence of an observer recording activity and making timings with a stopwatch is likely to influence the behaviour of at least some pedestrians. Working on high-speed roads requires careful attention to safety. Full precautions were taken when mounting the cameras and changing cassettes, for example by wearing high visibility jackets etc. Equivalent precautions could not be taken during direct observations without causing potential distraction to drivers as well as pedestrians. In addition the video recordings provided a permanent record of the activity that was fully analysed. An on-site observer would only have one chance to make all recordings of relevant factors including the fast moving vehicles. The video recordings covered the period from 07:30 to 18:30 on two days.

Figure 2-5 and Figure 2-6 show the typical view selected for video recording and analysis. The camera image gave a good view of the crossing and waiting area with enough of the vehicle approach to be able to determine whether there were any conflicts between vehicles and pedestrians. It also gave a view of the vehicle signals. It is not possible to combine the pedestrian signals in a single image with the required view of pedestrian and vehicle activity. Therefore, in the analysis, the state of the pedestrian signals was inferred from the state of the vehicle signals.

The results of the surveys of crossings of HA roads at Uttoxeter and Towcester have been reported to the HA and are not repeated here in detail, but relevant information from those surveys is included in the following results section. It should be noted that the survey technique at those sites was different from that used within this project because of the different project objectives. The aim of the study of the HA crossings was to assess over a long period, 6 months, the safety of people using the crossings. It was not possible to observe the crossings continuously for 6 months and so a technique was adopted that concentrated on people making positive use of the crossing. That is of those people who pressed the pedestrian demand button to request an invitation to cross. Anyone who crossed at the crossing without pressing the button was taken to not be a true user of the crossing. The provision of a traffic signal controlled crossing was assumed to have had little effect on their behaviour whilst crossing the road at that time. Consequently the video recordings of the HA crossings were not continuous records, but a set of 1 minute samples starting with each pedestrian button press.

3.2 Analysis

The analysis of the video recordings taken specifically for this project extracted information on vehicle and pedestrian flows, pedestrian behaviour and any conflicts between vehicles and pedestrians.

3.2.1 Vehicle flows

Vehicle flows during the morning peak, mid-day, afternoon off-peak and evening peak were extracted from the videos.

3.2.2 Pedestrian flows

Pedestrian flows were recorded throughout the observation period.
3.2.3  *Pedestrian behaviour*

The main objective of the analysis was to observe how pedestrians behaved when wanting to cross the road. The analysis separated those who crossed the road during the pedestrian phase from those who crossed the road completely, or partially during the vehicle green. As noted above, the analysis used the vehicle signals, rather than the pedestrian signals. Those who crossed in the vehicle green were further categorised into:

- Crossed in the vehicle green having pressed the pedestrian demand button
- Crossed in the vehicle green without pressing the pedestrian demand button
- Started to cross in the vehicle green, but completed the crossing after the end of the vehicle green, typically anticipating the end of the vehicle green and reacting to a gap in the vehicular traffic quicker than the signals.

The time spent waiting at the kerb by each pedestrian was noted and for those who crossed during the vehicle green the time gap between the pedestrian crossing and the next vehicle to arrive was recorded to the nearest second. For multi-lane sites the time gap was measured for each lane, that is, the time between the pedestrian crossing lane 1 and the next vehicle to arrive in the crossing zone in lane 1, similarly for lane 2 and lane 3 if there was one. The recorded time gap was the smallest of the time gaps for the individual lanes. Time gaps of greater than 9 seconds were not measured individually, simply recorded as 9 seconds or greater.

3.2.4  *Conflicts*

The observers looked for conflicts between vehicles and pedestrians throughout the video records.

3.3  Results

3.3.1  *Vehicle flows*

All the sites had appreciable flows as shown in Table 3-1

<table>
<thead>
<tr>
<th>Site</th>
<th>Minimum flow during observation period</th>
<th>Maximum flow during observation period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ferring</td>
<td>1000</td>
<td>1650</td>
</tr>
<tr>
<td>Birmingham</td>
<td>1200</td>
<td>2150</td>
</tr>
<tr>
<td>Nottingham</td>
<td>1400</td>
<td>2100</td>
</tr>
<tr>
<td>Leicester</td>
<td>1150</td>
<td>2700</td>
</tr>
</tbody>
</table>

3.3.2  *Numbers of people crossing the road*

Table 3-2 shows the numbers of people using the surveyed crossing facilities split by the state of the traffic signals when people crossed. The numbers of people using the crossing facilities varied considerably between sites as shown by the total column. Cyclists crossing at the signals, normally riding across, have been included with pedestrians at all sites, although not all sites were combined pedestrian and cyclist crossings. The totals for the junction and stand-alone crossing at Ferring would be identical except that there was a camera fault that resulted in the loss of just over two hours of data from the junction side of the carriageway. For the other sites it can be seen that the crossings have
been installed where there is pedestrian demand as the numbers using the stand-alone crossings are greater than at the nearby junctions. It is also clear that the proportion crossing in the vehicle green, that is, against the pedestrian signals is considerably greater at the stand-alone crossings than at the corresponding signal controlled junctions.

The need to find high-speed sites meant that all the sites surveyed were on dual-carriageways. Consequently, those pedestrians and cyclists who crossed at junctions had a longer vehicle red time during which to cross the stopline side of the carriageway, during both the pedestrian stage and the main road red, than did those crossing at the stand-alone crossing. This extra protected time resulted in both shorter delays waiting for a protected period in which to cross and fewer people choosing to cross against the signals.

As noted in the description of the Ferring crossing, all the horse riders waited for an invitation to cross and the same behaviour was observed at the crossing of the A43 at Towcester. Presumably horse riders are very reluctant to cross fast roads without the vehicular traffic having been stopped and so minimising the risk of their horses reacting dangerously to vehicles.

Overall cyclists are more likely to cross against the signals than are pedestrians and to do so without pressing the demand button, but the results are not consistent across all sites. It is not surprising that cyclists are somewhat more likely to cross against the signals than are pedestrians as they can cross the road in a shorter time and therefore safely cross in smaller gaps than can pedestrians. It may also be that cyclists have difficulty manoeuvring their bicycles into a position where they can press the demand button and so are more willing to wait for and take a gap in the vehicular traffic without pressing the button.

Table 3-2: Numbers crossing by state of the signals (people per hour)

<table>
<thead>
<tr>
<th>Site</th>
<th>Crossing type</th>
<th>Users</th>
<th>Vehicle red</th>
<th>Anticipating vehicle red</th>
<th>Vehicle green after button press</th>
<th>Vehicle green without button press</th>
<th>Total</th>
<th>Percent wholly in vehicle green</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ferring</td>
<td>Junction</td>
<td>Pedestrians</td>
<td>2.5</td>
<td>0.9</td>
<td>0.1</td>
<td>0.1</td>
<td>3.7</td>
<td>6%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cyclists</td>
<td>2.0</td>
<td>0.5</td>
<td>0.1</td>
<td>0.3</td>
<td>2.9</td>
<td>14%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Horse riders</td>
<td>1.6</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>1.6</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total</td>
<td>6.1</td>
<td>1.4</td>
<td>0.2</td>
<td>0.5</td>
<td>8.2</td>
<td>8%</td>
</tr>
<tr>
<td></td>
<td>Stand-alone</td>
<td>Pedestrians</td>
<td>2.6</td>
<td>0.1</td>
<td>0.5</td>
<td>0.5</td>
<td>3.7</td>
<td>28%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cyclists</td>
<td>0.9</td>
<td>0.0</td>
<td>0.8</td>
<td>1.0</td>
<td>2.7</td>
<td>67%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Horse riders</td>
<td>1.8</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>1.8</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total</td>
<td>5.3</td>
<td>0.1</td>
<td>1.3</td>
<td>1.5</td>
<td>8.2</td>
<td>35%</td>
</tr>
<tr>
<td>Birmingham</td>
<td>Junction</td>
<td>Pedestrians</td>
<td>6.4</td>
<td>0.2</td>
<td>0.0</td>
<td>0.1</td>
<td>6.8</td>
<td>2%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cyclists</td>
<td>0.9</td>
<td>0.0</td>
<td>0.0</td>
<td>0.1</td>
<td>1.0</td>
<td>8%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total</td>
<td>7.3</td>
<td>0.2</td>
<td>0.0</td>
<td>0.2</td>
<td>7.8</td>
<td>3%</td>
</tr>
<tr>
<td></td>
<td>Stand-alone</td>
<td>Pedestrians</td>
<td>13.6</td>
<td>0.5</td>
<td>2.4</td>
<td>4.3</td>
<td>20.8</td>
<td>32%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cyclists</td>
<td>1.3</td>
<td>0.0</td>
<td>0.0</td>
<td>0.5</td>
<td>1.8</td>
<td>27%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total</td>
<td>15.0</td>
<td>0.5</td>
<td>2.4</td>
<td>4.7</td>
<td>22.6</td>
<td>32%</td>
</tr>
</tbody>
</table>
The numbers crossing and the proportion choosing to cross during the vehicle green can be compared with the results from the stand-alone crossings on the high-speed trunk roads at Uttoxeter and Towcester in Table 3-3. The numbers using the crossing at Uttoxeter were a little lower than at most of the stand-alone sites surveyed, with the proportion crossing during the vehicle green at the low end of the range observed at the sites in Table 3-2. Relatively few people used the crossing at Towcester, but the signals provided a safe crossing for bridleway users, who included equestrians, at the site.

Table 3-3. Numbers crossing at HA project sites

<table>
<thead>
<tr>
<th>Site</th>
<th>Number crossing per hour</th>
<th>Proportion crossing in vehicle green</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uttoxeter</td>
<td>10.5</td>
<td>30%</td>
</tr>
<tr>
<td>Towcester</td>
<td>4.4</td>
<td>22%</td>
</tr>
</tbody>
</table>

There is considerable variation between sites; 30% to 45% of pedestrians crossed during the vehicle green at the stand-alone crossings, dropping to 5% to 25% at the junction sites surveyed. It is noticeable that rather more people crossed in the vehicle green without first pressing the pedestrian demand button than crossed in the vehicle green after pressing the button. One possible explanation is that pedestrians and cyclists approaching the crossing look to see whether it is possible to cross the road and if it is possible in the near future cross without bothering to demand the pedestrian stage. Should it not be possible, then the pedestrian stage is probably demanded, but a few pedestrians were seen to wait a long time to cross and did not press the demand button. Sometimes pedestrians and cyclists, who have demanded the pedestrian stage, cross before the pedestrian stage occurs, or anticipate the start of the pedestrian stage as was particularly likely at the Ferring and Nottingham junction sites.
As described in section 3.1, recording of behaviour at the HA sites was restricted to one-minute periods after each button press. Consequently vehicle flows were not monitored at these sites.

### 3.3.3 Waiting times

The time spent waiting at the kerbside before crossing the road was measured for each person using the crossings and analysed by the state of the signals when they crossed using the same categories as for the numbers of people crossing. In addition for each person who crossed during the vehicle green, the gap to the next vehicle was measured as described in section 3.2.3. The results are presented in Table 3-4.

At most sites the waiting times for those crossing in the vehicle red were considerably longer at the stand-alone crossings than at the junctions. The main reason for this difference is that the waiting times were measured for pedestrians waiting to cross one carriageway of a dual carriageway, the carriageway on which vehicles approached the junction. Therefore, the vehicle red in which pedestrians could cross that carriageway was the whole of the red to vehicles on that approach, the normal red whilst conflicting traffic movements have right-of-way plus any all-red pedestrian period. At the stand-alone crossings, the vehicle red was much shorter, just the length of the pedestrian stage. The exception to this pattern was at Nottingham, where the waiting times were similar at the junction and the Pelican. The reason is a combination of factors: both sets of signals were under UTC control, but the Pelican was able to double-cycle under SCOOT control, the region cycle time was long and the red time to vehicles at the junction was short. That means that for much of the day when SCOOT double-cycled the Pelican there were two opportunities for pedestrians to cross for each one at the junction, resulting in shorter waiting times for an invitation to cross. In addition, the short vehicle red at the junction meant that, unlike the other sites, there was not a long period in which pedestrians could arrive and cross in the vehicle red without delay. The average waiting time at the Pelican was still quite long as the junction cycle time was long.

**Table 3-4: Kerbside delays (seconds) to users of the crossings, standard deviations in brackets**

<table>
<thead>
<tr>
<th>Site</th>
<th>Crossing type</th>
<th>Users</th>
<th>Vehicle red</th>
<th>Anticipating vehicle red</th>
<th>Vehicle green after button press</th>
<th>Vehicle green without button press</th>
<th>Average</th>
<th>Mean gap behind those crossing in vehicle green</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Pedestrians</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Junction</td>
<td></td>
<td>14.0 (13.4)</td>
<td>8.9 (5.9)</td>
<td>15.5 (14.8)</td>
<td>0.7 (0.6)</td>
<td>12.3 (12.0)</td>
<td>4.6 (3.5)</td>
<td>(</td>
</tr>
<tr>
<td>Ferring</td>
<td></td>
<td>26.6 (21.0)</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>26.6</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>16.4 (17.1)</td>
<td>13.7 (14.9)</td>
<td>10.0 (10.9)</td>
<td>0.5 (1.0)</td>
<td>14.9 (16.5)</td>
<td>6.1 (3.2)</td>
<td></td>
</tr>
</tbody>
</table>

|               |               | Cyclists     | 11.0 (14.2)| 22.5 (21.6)              | 4.5 (3.5)                        | 0.4 (1.1)                        | 11.7 (15.8)|                                               |
|               |               | Horse riders | 26.6 (21.0)| N/A                     | N/A                              | N/A                              | 26.6     |                                               |
|               |               | Total        | 16.4 (17.1)| 13.7 (14.9)             | 10.0 (10.9)                      | 0.5 (1.0)                        | 14.9 (16.5)|                                               |

|               |               | Pedestrians  | 37.1 (6.8) | 4.0 (5.7)               | 8.8 (5.7)                        | 2.8 (3.5)                        | 27.5 (15.6)|                                               |
|               |               | Cyclists     | 34.4 (12.8)| N/A                     | 11.2 (10.2)                      | 5.0 (7.1)                        | 16.5 (16.3)|                                               |
|               |               | Horse riders | 42.3 (20.0)| N/A                     | N/A                              | N/A                              | 42.3 (20.0)|                                               |
|               |               | Total        | 38.4 (13.6)| 4.0 (5.7)               | 10.2 (8.6)                       | 4.3 (6.2)                        | 27.2 (19.2)|                                               |
Average waiting times at the stand-alone crossings were all between 30 and 40 seconds for those who
waited for the pedestrian stage. This delay suggests that there were not many occasions when the
signals responded to a gap in the vehicular traffic. Such behaviour is quite common at high-speed
sites under VA control because of the action of SA / SDE extending the green. At the sites under UTC
control (all except Ferring), the occurrence of the pedestrian green would be controlled by the UTC

<table>
<thead>
<tr>
<th>Site</th>
<th>Crossing type</th>
<th>Users</th>
<th>Vehicle red</th>
<th>Anticipating vehicle red</th>
<th>Vehicle green after button press</th>
<th>Vehicle green without button press</th>
<th>Average</th>
<th>Mean gap behind those crossing in vehicle green</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Birmingham</td>
<td>Junction</td>
<td>Pedestrians</td>
<td>17.2 (17.2)</td>
<td>17.6 (12.0)</td>
<td>31.0 (N/A)</td>
<td>14.5 (9.2)</td>
<td>17.3 (14.1)</td>
<td>4.3 (3.2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cyclists</td>
<td>11.4 (10.0)</td>
<td>N/A</td>
<td>N/A</td>
<td>6.5 (6.4)</td>
<td>11.0 (9.7)</td>
<td>6.5 (4.9)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total</td>
<td>16.5 (13.9)</td>
<td>17.6 (12.0)</td>
<td>31.0 (N/A)</td>
<td>10.5 (7.9)</td>
<td>16.4 (13.4)</td>
<td>5.2 (3.6)</td>
</tr>
<tr>
<td></td>
<td>Stand-alone</td>
<td>Pedestrians</td>
<td>39.6 (19.5)</td>
<td>23.1 (11.0)</td>
<td>26.4 (12.5)</td>
<td>12.2 (9.2)</td>
<td>32.1 (20.4)</td>
<td>5.2 (2.1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cyclists</td>
<td>36.8 (14.3)</td>
<td>N/A</td>
<td>30.0 (N/A)</td>
<td>9.0 (7.6)</td>
<td>29.7 (17.5)</td>
<td>5.8 (2.0)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total</td>
<td>39.3 (19.1)</td>
<td>23.1 (11.0)</td>
<td>26.4 (12.4)</td>
<td>11.9 (9.1)</td>
<td>31.9 (21.5)</td>
<td>5.2 (2.1)</td>
</tr>
<tr>
<td>Nottingham</td>
<td>Junction</td>
<td>Pedestrians</td>
<td>28.6 (19.6)</td>
<td>20.7 (14.1)</td>
<td>41.2 (22.1)</td>
<td>31.2 (25.1)</td>
<td>28.8 (20.0)</td>
<td>8.5 (2.5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cyclists</td>
<td>30.8 (22.7)</td>
<td>34.0 (20.7)</td>
<td>23.0 (9.6)</td>
<td>26.3 (25.2)</td>
<td>30.4 (20.0)</td>
<td>8.6 (3.1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total</td>
<td>28.9 (20.2)</td>
<td>24.1 (16.7)</td>
<td>38.5 (21.6)</td>
<td>29.7 (24.7)</td>
<td>29.1 (21.1)</td>
<td>8.5 (2.6)</td>
</tr>
<tr>
<td></td>
<td>Stand-alone</td>
<td>Pedestrians</td>
<td>31.0 (14.1)</td>
<td>22.6 (11.3)</td>
<td>18.8 (6.2)</td>
<td>11.1 (6.0)</td>
<td>25.4 (14.9)</td>
<td>6.2 (2.5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cyclists</td>
<td>32.6 (16.3)</td>
<td>36.0 (31.1)</td>
<td>17.6 (10.1)</td>
<td>8.8 (8.1)</td>
<td>25.0 (17.0)</td>
<td>7.0 (2.6)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total</td>
<td>31.4 (14.7)</td>
<td>24.0 (13.6)</td>
<td>18.3 (9.0)</td>
<td>10.4 (9.5)</td>
<td>25.3 (16.6)</td>
<td>6.4 (2.6)</td>
</tr>
<tr>
<td>Leicester</td>
<td>Junction</td>
<td>Pedestrians</td>
<td>25.2 (15.4)</td>
<td>12.0 (0)</td>
<td>12.0 (1.4)</td>
<td>27.3 (20.9)</td>
<td>24.6 (16.5)</td>
<td>6.0 (2.2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cyclists</td>
<td>15.2 (12.7)</td>
<td>N/A</td>
<td>13.0 (1.4)</td>
<td>12.2 (7.4)</td>
<td>14.7 (11.8)</td>
<td>6.4 (2.6)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total</td>
<td>19.9 (15.0)</td>
<td>12.0 (0)</td>
<td>12.5 (1.3)</td>
<td>21.9 (18.6)</td>
<td>19.8 (15.0)</td>
<td>6.1 (2.6)</td>
</tr>
<tr>
<td></td>
<td>Stand-alone</td>
<td>Pedestrians</td>
<td>38.7 (11.1)</td>
<td>34.4 (2.9)</td>
<td>16.9 (6.5)</td>
<td>12.0 (10.1)</td>
<td>28.1 (15.6)</td>
<td>5.7 (2.8)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cyclists</td>
<td>45.1 (31.8)</td>
<td>N/A</td>
<td>19.5 (10.6)</td>
<td>11.0 (12.1)</td>
<td>29.7 (29.0)</td>
<td>6.4 (3.0)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total</td>
<td>39.3 (14.1)</td>
<td>34.4 (29.0)</td>
<td>17.0 (6.6)</td>
<td>11.8 (10.3)</td>
<td>28.2 (19.0)</td>
<td>5.8 (2.8)</td>
</tr>
</tbody>
</table>
system. If the crossing is single cycled within the UTC there will be only one opportunity for the pedestrian stage per cycle, double cycling will give two opportunities. With long cycle times, the delay before the occurrence of the pedestrian stage can be long for single cycled sites. As noted above, the results for Nottingham show the advantage of double-cycling crossings where possible.

As an example of the delays by crossing behaviour, Figure 3-1 and Figure 3-2 show the data from Nottingham of the proportions of pedestrians in each category (those who crossed wholly in the vehicle red etc.) against their waiting time. It can be seen that a relatively large proportion of those who did not press the demand button had a short delay, particularly at the stand-alone crossing. The figures do not show the numbers in each category, only the proportion of the total people in that category who were delayed by a particular time.

![Nottingham junction, proportion of pedestrians crossing by signal status](chart1.png)

**Figure 3-1: Pedestrian delays at the Nottingham junction**

![Nottingham stand-alone crossing, proportion of pedestrians crossing by signal status](chart2.png)

**Figure 3-2: Pedestrian delays at the Nottingham stand-alone crossing**

At the junctions in Nottingham and Leicester, the delays for pedestrians and cyclists who waited for the vehicle green were appreciably more than those at Ferring and Birmingham (29 and 20 seconds compared with 16 and 17). At these sites with the longer waiting times a higher proportion of people
crossed the road during the vehicle green (12% and 23% respectively than at the junctions with shorter waiting times (8% and 3%). Similarly many more people crossed in the vehicle green at the stand-alone crossings where the waiting times were considerably longer than at the junctions.

There was no evidence of undue risk taking by those who crossed during the vehicle green. The average time between a pedestrian clearing the conflict zone and the arrival of a car in the zone was about 6 seconds (the gaps were measured to the nearest second) with no consistent difference between stand-alone crossings and junctions. Table 3-5 shows the minimum and 15\textsuperscript{th} percentile gaps at the various sites. The 15\textsuperscript{th} percentile is the gap that was accepted by only 15% of those crossing in the vehicle red; 85% of those crossing required a longer gap. At a few sites the minimum gap was measured to be 1 second, but in none of these cases was the pedestrian or cyclist judged to be in danger of collision with the vehicle. At the junction in Nottingham there was one occasion where a cyclist left a very short gap of 1 second before the next vehicle arrived. The car which was turning right at the lights had to brake to let the cyclist past, the car was travelling at a slow speed, so there was more inconvenience than real danger.

<table>
<thead>
<tr>
<th></th>
<th>Ferring</th>
<th>Birmingham</th>
<th>Nottingham</th>
<th>Leicester</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Junction</td>
<td>Stand-alone</td>
<td>Junction</td>
<td>Stand-alone</td>
</tr>
<tr>
<td>Minimum gap</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>15\textsuperscript{th} percentile</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

The method of signal control and the volume of vehicular traffic had a considerable impact on pedestrian behaviour. At the Ferring site, the operation of SA/SDE meant that the green time to the main road was frequently held when there were appreciable gaps in the traffic. Consequently 8% of the pedestrians crossed the road on the junction side during vehicle green. At Birmingham, the traffic was heavy and travelled in platoons from the upstream junction. SCOOT control managed the progression of these platoons well. The result was that at the start of vehicle green the vehicle flow through the junction was very heavy, with no opportunities for pedestrians to cross. Towards the end of green there were a few gaps in the vehicular traffic, but not many as the green length was well controlled with little spare green. Only 3% of the pedestrians crossed in the vehicle green at this site.

The stand-alone crossing was also under SCOOT control with its cycle time the same as that of the neighbouring junctions. Consequently the time between invitations to cross to pedestrians was longer than would have been the case if the crossing had been operating independently, rather than under UTC control. With the vehicular traffic travelling in dense platoons, there were opportunities for pedestrians to cross in the vehicle green after the main platoon had passed the crossing. Consequently a much larger proportion, 32%, crossed in the vehicle green. It was also observed that several pedestrians re-pressed the demand button at least once whilst waiting. Presumably they were unhappy with the length of time that they had been waiting and re-pressed the button to ensure that the demand had been registered, or perhaps hoping that extra presses would bring the pedestrian stage in earlier.

Nottingham, where the Pelican crossing was double-cycled, was the only place where the waiting times for pedestrians and cyclists crossing in the vehicle red were similar at the junction and stand-alone crossing. At all the other sites, the average wait was considerably longer at the stand-alone crossing than the junction. It is interesting to note that even at Nottingham, the proportion crossing in the vehicle green at the stand-alone crossing was nearly three times as high as the proportion at the junction. The gaps in the vehicular traffic chosen by those who crossed in the vehicle green were
similar at the two installations. It appears, at least at this site, that there was more opportunity, or temptation, to cross against the signals at the stand-alone crossing than at the junction, even though the Pelican was double-cycled. The reasons for the different behaviour are not known. One possible factor that could have inhibited crossing against the signals at the junction was the presence of a protected right turn stage on the approach. At times there were gaps in the arrival flow of vehicles, but a queue of right-turners held at a red light. Pedestrians may have been unwilling to take advantage of the gap in straight-ahead vehicles because they would have had to cross in front of the right-turn queue, which could be about to receive a green signal.

The lengths of the vehicle red periods at the Pelican and junction determine the length of the opportunity to cross in the vehicle red each cycle. As the Nottingham sites were under SCOOT control the lengths can change in each cycle. However, from a sample of timings the junction ran at a 96 second cycle time for much of the day with a main road vehicle red time of 21 seconds. The red did increase during some cycles but was under 30 seconds in all the sampled cycles. The vehicle red at the Pelican was shorter, 12 seconds, but there were two opportunities for a vehicle red in each cycle. Therefore, the potential length of vehicle red each cycle was similar at the junction and Pelican, when it was double-cycled.

3.3.4 Incidents and conflicts

As noted above, there was one occasion, at the junction site in Nottingham, where a right-turning vehicle braked to ensure the safety of a crossing cyclist. No other significant conflicts were observed at any of the sites, however, various incidents were noted:

- At the Birmingham junction, one pedestrian was observed to start to cross after the end of the pedestrian green and to turn back to regain the footway as the vehicles started to move at the start of their green.
- A few people, 5 in Birmingham, 5 in Leicester and one in Nottingham, were observed to cross the road close to the stand-alone crossings, but not at the crossing.
- Several runners and joggers were observed, but they did not take noticeable risks when crossing.
- One cyclist was observed to wait for 2 minutes at the Leicester stand-alone crossing without pressing the button. A second cyclist arrived nearly 1½ minutes after the first and pressed the button. They both crossed in the ensuing vehicle red.

3.4 Conclusions

No obviously unsafe behaviour was observed at any of the stand-alone crossings or junctions. There is no evidence that pedestrians and cyclists who crossed against the traffic signals chose to cross in different length gaps at junctions or at stand-alone crossings. It was expected that pedestrians and cyclists would be more likely to cross against the signals at sites with a long wait for an invitation to cross and this behaviour was observed. A further indication of frustration with long waiting times was witnessed at the stand-alone crossing in Birmingham where pedestrians were seen to re-press the demand button whilst waiting for the signals to change.
4 Driving simulator

The second stage of the project investigated drivers’ behaviour. In particular, do drivers approach signal controlled crossings differently from how they approach traffic signalled junctions, and is there any difference in their response to the traffic lights at the two types of installation? The TRL driving simulator was used to provide a safe situation to explore drivers’ responses to traffic signals at stand-alone crossings and junctions when the signals changed to amber as the driver approached them. The results were analysed to determine any change in response to the signals and caution of approach between junctions and stand-alone crossings.

The TRL driving simulator uses a real, full-size car with all displays and controls operating as in a normal car. A sophisticated projection and sound system give a life-sized realistic driving environment, and a vibration and motion base give heave, pitch and roll to the car body, and add to the sense of movement experienced by the subject in the virtual world produced. The car is surrounded by three screens to the front providing 210º horizontal x 40º vertical field of view and one similar sized screen to the rear providing a 70º horizontal x 40º vertical field of view, enabling use of all three of the vehicles mirrors.

The vehicle’s behaviour on the simulated route is controlled by the vehicle’s controls. The projected scene responds to the speed and orientation of the vehicle as controlled by the driver. Figure 4-1 presents a view of the simulator car and the front projection screens. The clarity and brightness of the projections in the figure is reduced by the lighting of the car for the photograph.

Using the simulator rather than an on-road trial had two major benefits: safety and efficiency. A series of drivers was presented with the same set of decisions as to whether to stop or continue through the signals when they changed from green to amber as the car was at pre-set distances from the stopline. The safe environment of the simulator meant that if a driver made a wrong decision, there was no danger of an accident. The efficiency came from the ability to present many more difficult decisions to drivers in one drive of about half an hour than would occur on the road. In addition the same set of decisions was presented to all the drivers, which would not happen on the road.
The disadvantage of the simulator is that, although it is very realistic, it is still fundamentally an artificial situation. It is known that overall drivers drive somewhat faster in the simulator than they do on the road. The differences in driver behaviour between the simulator and normal driving are not, however, such that they would invalidate the comparison of behaviour approaching traffic signals at junctions and stand-alone crossings. Further, the experiment resulted in drivers needing to make more stopping decisions than they would in reality. Hence they could be more alert on their approach to the stop line than they would under normal driving conditions.
5 Test routes and procedures

5.1 Route design
The objective of the study was to examine drivers’ behaviour approaching traffic signals at the upper end of speeds where signals could be installed within the guidelines, that is, with cruise speeds in the range of 50 to 70 mph (80 to 113 km/h). To meet this objective, two routes were developed for the simulator, one a dual-carriageway and one a single-carriageway. Both roads were unrestricted apart from the national speed limit, 70 mph (113 km/h) for the dual and 60 mph (97 km/h) for the single-carriageway. The intention was that drivers should feel comfortable driving along the roads at or near the national speed limit so that their behaviour could be studied when approaching signals at cruise speeds in the desired range of 50 to 70 mph (80 to 113 km/h).

Each route had 12 signal controlled junctions and 12 Puffin (stand-alone) crossings along its length. The routes were composed of free-running sections of about 1.5 km between 500m long sections with signals. The road geometry was flat and generally straight to provide ideal circumstances for the driver in terms of visibility. Some curves were placed between junctions, together with changes in surrounding scenery, to assist in maintaining the illusion of travelling on a real road. The environment encouraged high speed driving. As a result of building the route from sections it was possible to present each driver with an identical set of free-running sections, but different orders of junctions and Puffins to eliminate order effects from the survey design.

Automated cars were present on the simulated road system, but, on the dual-carriageway route, they were not allowed to travel on the same carriageway as the test car. On the single-carriageway route, automated cars travelled on the same road as the test car, but only in the opposite direction to it. Some automated cars were on the crossroads at the junctions and only crossed when they had priority and the test car had stopped. The automated vehicles created an impression of true road travel without interfering in the driver’s decision making process and thereby introducing further confounding variables to take account of in the analysis.

There were few buildings close to the road in the linking sections of route, to avoid inhibiting drivers’ speed. The scene around the crossings and junctions, however, was designed with shops on one side of the road and housing on the other to provide a realistic situation where pedestrians would be expected to cross the road.

Standard road signs and markings were used on the approach to all the junctions and Puffin crossings. That is, the triangular warning sign for traffic signals and warning markings replacing the lane markings on the approach to the traffic signals. In addition, for the junctions, large advance primary route direction signs were used. The straight ahead destination and road number were consistent throughout each run. The final 250 metres section of the approach to all traffic signals was straight to give good visibility of the signals and standard pedestrian crossing markings were used at the signals.

The basic design principle was that the routes should be realistic, correctly marked and signed according to the relevant regulations and appear logical to the drivers, with traffic signals only where the surrounding scene suggested that signals might be expected.

5.2 Traffic signal control and trigger points
The objective of the traffic signal control was to investigate drivers’ reactions to signals changing from green to amber and then red as a function of the distance of the test car from the signals at the time of the green to amber change. There is a range of distances from the signals where drivers may feel in a dilemma as to whether to continue and hope to clear the junction before the start of red, or brake hard and have difficulty stopping before the stopline. This “dilemma zone” is a function of speed and the probability of an accident happening is highest for drivers making a decision in this zone, (Department for Transport, 2003).
The traffic signals were set to change as the simulated car passed a **trigger point** on the approach to the signals.

### Definition of Trigger Point:

Distance from the stop line when the signals changed from green to amber

On each run four different trigger points were used. Each trigger point was used twice at both Puffins and junctions. At the remaining four junctions and four Puffin crossings there was no trigger point, the signals remained green, so that drivers did not become habituated to stopping. The four trigger points were:

- **Change to amber just before the start of the dilemma zone**: 90 metres on 60 mph (97 km/h) road and 110 metres on 70 mph (113 km/h) road. At this distance almost all drivers were expected to stop.
- **Change to amber just inside the dilemma zone**: 75 metres on 60 mph (97 km/h) road and 90 metres on 70 mph (113 km/h) road. A more difficult decision, but most drivers expected to stop.
- **Change to amber approximately half way through the dilemma zone**: 60 metres on 60 mph (97 km/h) road and 70 metres on 70 mph (113 km/h) road. The most variation in stopping decisions was expected for this trigger point.
- **Change to amber near the end of the dilemma zone**: 40 metres on 60 mph (97 km/h) road and 45 metres on 70 mph (113 km/h) road. At this distance many drivers would decide to continue.

The trigger points were designed to provide a good sample of drivers’ decisions in the dilemma zone. Outside the dilemma zone the decisions are much more clear cut, presenting drivers with an amber signal very far from the signals, or very close to them would not provide any useful information about their behaviour.

As a result of this design, concentrating on decisions in the dilemma zone, drivers were subject to the traffic signals changing from green to amber in the dilemma zone much more frequently than they would be when driving on a real road. It was necessary to present each driver with so many difficult decisions to provide a sufficiently large sample of decisions to make conclusions about driver behaviour. However, the unusual frequency of traffic signals changing to amber could affect drivers’ behaviour. Two measures were taken to minimise the influence on drivers.

- Firstly, as stated above, 4 junctions and 4 Puffin crossings were included on each run at which the lights remained green, to prevent the drivers expecting to have to stop at each set of signals.
- Secondly, a “repeated measures” design was used to eliminate order effects. Three different orders of junctions and Puffin crossings with associated trigger points were developed for each route and the drivers were split between those routes. The order of junctions, Puffins and trigger points any one driver saw was different for the dual-carriageway from that used on the single-carriageway. The purpose of the design was that if drivers did change their behaviour as they experienced signals changing against them during the trial, this “learning” effect would not affect the conclusions about any difference in behaviour at stand-alone crossings and junctions.

### 5.3 Pedestrian behaviour

Groups of pedestrians were positioned in the waiting area for the crossing, at a reasonable distance from the edge of the road, at all sets of signals. The side of the road at which they waited was varied between the crossings on any one route. The positioning of the pedestrians was the same at the junctions and the stand-alone crossings to ensure consistency between the two types of traffic signal
installation. Any change in behaviour because a driver could see pedestrians waiting near the signals received the same stimulus at junctions and at stand-alone crossings.

To improve the realism of the simulation we wanted pedestrians to cross the road when the target car stopped. It was considered essential at the Puffin crossings that drivers could see a reason for stopping and for consistency the pedestrians waiting at junctions should also cross the road. Because of limitations on computing power it was only possible to have one pedestrian (strictly an autonomous vehicle shaped and dressed like a pedestrian with moving legs) cross the road at any one time. The behaviour of this pedestrian was considered to be sufficiently realistic to give drivers the impression of normal pedestrian behaviour. None of the subjects commented on the fact that only one of the waiting pedestrians actually crossed the road.

The walking pedestrian was carefully programmed to ensure that he did not step out from the kerb when there was a possibility of the test car not stopping. We did not want to compromise the trial by simulating collisions with pedestrians.

5.4 Test drivers

A total of 40 drivers, 20 male and 20 female, aged between 25 and 60 drove the test routes. Before conducting the trials, participants undertook a familiarisation session in the Driving Simulator. This involved a short drive in the simulator to get used to the vehicle and its controls.

A disadvantage of using the simulator is that participants are aware that they are involved in a trial and that something unusual is likely to happen. During the pilot trial, analysis of the questionnaires, which all participants completed after driving both routes, showed a potential concern. The particular subject approached all the signals very slowly because of a worry that a pedestrian would step out in front of the car making a collision very difficult to avoid. To allay such fears, the instructions given to the participants as they prepared to start the trial drives were strengthened to emphasise that the other road users and pedestrians would behave in a normal, safe manner. The participants were then asked to drive as they would normally.

5.5 Questionnaire

After the drivers had completed both test drives they were asked to complete a questionnaire. The main objectives of the questionnaire were:

- To explore participants’ attitudes towards signal controlled stand-alone crossings and junctions and any differences in their perceptions of the two types of traffic signal installation.
- To ask about any differences in the subjects’ driving behaviour in the simulator from their normal driving.
- To ask whether the presence of pedestrians waiting near signals affects their driving behaviour.
- To enquire about the difficulty experienced in deciding whether or not to stop at the traffic signals.

This questionnaire was analysed separately to examine differences in driver perceptions of the two types of crossing. It was included in the simulator analysis for two reasons. Firstly, it assisted in identifying drivers whose behaviour was outside the norm: i.e. outliers. Secondly, it indicated the level of difficulty they encountered and the suitability of the decisions they made. This was investigated to see if it was related to the driving style they used in the simulator.
6 Data reduction and verification

6.1 Data reduction

The objective was to analyse differences in drivers’ responses to traffic signals at stand-alone crossings and junctions. Two main differences were postulated:

- Different approach speeds, slowing down more when approaching one type of signals
- Different probability of stopping when presented with an amber signal close to the stopline.

Information was required to test these hypotheses. The driving simulator produces a wealth of information. The vehicle’s position, in 3 dimensions, speed and position along the centre of the road are output each 1/60th of a second, together with data on the driver’s use of the vehicle’s brakes, clutch, accelerator and indicators. This data was reduced to provide:

- Speed profiles from 250m in advance of each set of signals to 30 metres after passing the stopline
- Acceleration profiles from 250m in advance of each set of signals to 30 metres after passing the stopline
- Other relevant information on the driver’s actions and use of the controls, relative to both the vehicle’s position on the road and the state of the traffic signals.

The answers to the post-drive questionnaires were also coded for analysis.

6.2 Data verification

Before analysing the data in detail they were verified to check for any errors in coding, but more importantly to examine the behaviour of individual drivers. One known difficulty with using driving simulators, as described in section 4, is that the simulator is an artificial situation. Although it provides a very realistic driving environment, an individual may not drive in the simulator in a way that is typical of real world driving. Including drivers who were obviously driving very atypically would reduce the robustness of any conclusions from the study. Approach speeds and stopping decisions were the main criteria used to identify possible outliers, those whose driving characteristics were so far from the norm as to be very unrepresentative of real world behaviour. Two drivers were found to approach the traffic signals with a complete lack of caution, not slowing on the approach and continuing through almost all signals without attempting to stop. Anyone driving in a similar manner, showing a complete lack of caution at all times, on real roads would be at high risk of a serious accident and would almost certainly be involved in at least a rear end shunt very frequently. They were excluded from the analysis.

Conversely, three drivers were found to behave with excessive caution compared with normal drivers. They approached the signals so slowly that they were easily able to stop even at the shortest trigger distances. These drivers were excluded from the analysis as they would not provide any information about the relative safety of stand-alone crossings and junctions on high-speed roads. Their driving was not relevant to the problems of drivers failing to stop at traffic signals on high-speed roads and the objectives of the project.
7 Analysis of drivers’ behaviour

As described in the introduction, the DfT guidelines for installing traffic signals on high speed roads are different for installations at junctions, which can have pedestrian facilities, and at stand-alone pedestrian crossings. There is an underlying implication that drivers’ show more caution when approaching a crossing at a junction, than one located in the middle of a link. This study permitted the safe investigation of the behavioural differences between drivers approaching both types of crossings on identical roads (with the same speed limit). In addition to varying the types of crossing, participants also drove on two roads: a single carriageway road with a 60 mph (96 km/h) speed limit, and a dual carriageway with a 70 mph (113 km/h) limit. Any consistent behavioural differences on both types of roads would imply that the types of pedestrian crossing influence drivers under a range of conditions.

During each journey they encountered twelve occurrences of each type of pedestrian crossing, and their approach behaviour was recorded in terms of speed. Then their reaction to the signals changing was measured in terms of whether they stopped, or continued over the crossing, the acceleration and decelerations used, and reaction time if stopping (i.e. the time from signal change until applying the brake).

Such reactions depend on the distance the driver is from the pedestrian crossing at the time the lights change to amber. At close distances all drivers would be expected to continue through the junction, as they are able to clear within the amber, but unable to stop at acceptable deceleration rates. Far from the junction they can easily stop and not pass the crossing before the start of red. Between these extremes lies the “dilemma zone”, where decisions are more difficult. It is in this zone that driver reactions are under the most pressure, and any differences in reactions should be evident.

Consequently, the pedestrian lights either did not change, or were set to change at a number of fixed distances within this dilemma zone. Drivers encountered a number of pedestrian crossings and junctions where the lights did not change on the approach. They were included in the experiment to stop drivers anticipating the change and using excess caution in response.

As explained in the previous section, some drivers behaved so abnormally that they had to be excluded from the analysis. These either approached with no caution, continuing over the pedestrian crossing irrespective of the distance at which the lights changed, or were overly cautions, slowing on the approach to a degree where they almost stopped at all traffic signals, irrespective of the state of the lights. Removing these outlier observations resulted in a sample size of 70 for each combination of trigger distance, road type and signal installation.

Driver behaviour was analysed for each “event,” a particular combination of:

- Driver
- Road type (single or dual carriageway)
- Traffic signal type (junction or stand-alone pedestrian crossing)
- Trigger distance
- For example, driver E on the dual carriageway approaching a stand-alone crossing with a trigger distance of 110 metres constitutes an event.

Only events where the signals were green at the specified distance from the stopline were considered when analysing approach speed.

7.1 Approach speeds

Participants in the experiment were asked to drive normally during the simulation. The objective was that many would drive near to the speed limit, as they would on a normal drive. Therefore the observed speeds on the two runs should vary by the 10 mph (16 km/h) difference between the two simulated roads.
Table 7-1: Approach speeds at 160m (km/h)

<table>
<thead>
<tr>
<th></th>
<th>Mean Speed</th>
<th>85th Percentile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single carriageway stand-alone</td>
<td>90</td>
<td>101</td>
</tr>
<tr>
<td>Single Carriageway junction</td>
<td>86</td>
<td>99</td>
</tr>
<tr>
<td>Single carriageway overall</td>
<td>88</td>
<td>100</td>
</tr>
<tr>
<td>Dual-carriageway stand-alone</td>
<td>94</td>
<td>112</td>
</tr>
<tr>
<td>Dual-carriageway junction</td>
<td>91</td>
<td>109</td>
</tr>
<tr>
<td>Dual carriageway overall</td>
<td>93</td>
<td>111</td>
</tr>
</tbody>
</table>

Table 7-1 shows that different approach speeds were obtained on the dual and single carriageway routes as desired. Approach speeds were measured at 160 metres from the signals, the distance in advance of the signals that is used when assessing the need for speed assessment or discrimination control (Departmental advice note TA22/81). It was suitable for the needs of this study as it is before the start of the dilemma zone, but after signing has clearly indicated to the drivers that they are approaching a junction or stand-alone (Puffin) crossing. The approximate 10 km/h (6 mph) difference in the 85th percentile of speed on the two roads indicates that more drivers slightly exceeded the speed limit on the single carriageway road (85th percentile was approximately 62 mph or 100 km/h), whilst most drove slightly under the limit on the dual carriageway (85th percentile was approximately 69 mph or 111 km/h).

The difference in the average speeds between the single and dual carriageway roads was less than the difference in the 85th percentile speeds. The underlying distribution of speeds shows that this was owing to the wider variation of speeds observed on the dual carriageway (Figure 7-1). This resulted in 95% of the observations on the single carriageway road being in a band 13 km/h narrower than those on the dual carriageway.

Figure 7-1: Speed frequency distributions over all observations (km/h)
Figure 7-2 shows the average approach speed as a function of distance from the stop line for vehicles approaching the two different types of signal and on the two types of road. The approach speeds shown are the averages for all drivers who were shown a green signal at that distance.

Drivers reduced their speed whilst approaching the stop line. Then, if the signals remained green close to the stop line, they decided that the signals were not going to change and require them to stop, so they accelerated.

Drivers approached junctions at a somewhat lower speed (with more caution) than stand-alone (Puffin) crossings on both types of road. The differences in speed approaching the two types of signal installation were statistically significant at the 95% level from 250 metres to:

- 120 metres before the stop line on the dual carriageway and
- 80 metres before the stop line on the single carriageway.

Closer to the stop line the variability of approach speed increases and the differences are less significant. On seeing a junction in the distance they slowed down by approximately 3km/h (2mph) more than when approaching a stand-alone crossing.

Similar profiles showing how the 85th percentile of approach speed varied with distance from the stop line are shown in Figure 7-3.
In agreement with the difference in average speed, the 85th percentile of speed was 3 to 4 km/h (2 to 3 mph) less when approaching a junction rather than a stand-alone crossing within the same speed limit. This difference in both the average approach speed and the 85th percentile is indicative that the distribution of speeds has moved and therefore drivers generally use less caution when approaching a stand-alone crossing, than when they approach a signal controlled junction. Clearly, the difference in approach speed is less than the 15 mph (24 km/h) difference contained in the current advice. However, approach speed is only one element influencing the safety of pedestrians on the crossing. The following sections examine other aspects of the driver’s decision.

7.2 Stopping Decisions

Measured approach speeds imply that drivers’ used less caution when approaching a stand-alone crossing than a junction. Both the difference in approach speed, and the underlying difference in applied caution, would be expected to influence how drivers react to the signals changing. Any differences in stopping decisions should be more evident in the central section of the dilemma zone. Drivers have to make the most difficult decisions in this area, and their frame of mind can have the most influence. Table 7-2 contains the percentage of drivers that stopped for all trigger distances, and those that stopped at two of the trigger distances approximately in the middle of the dilemma zone.

**Table 7-2: Percentage of drivers stopping**

<table>
<thead>
<tr>
<th>Road type</th>
<th>Trigger Distance (m)</th>
<th>Percent stopping</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Stand-alone</td>
</tr>
<tr>
<td>Single carriageway</td>
<td>ALL</td>
<td>54.5%</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>15.9%</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>44.3%</td>
</tr>
<tr>
<td>Dual carriageway</td>
<td>ALL</td>
<td>62.5%</td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>52.9%</td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>80.0%</td>
</tr>
</tbody>
</table>
Overall drivers stopped more often when approaching a junction than a stand-alone crossing: they decided to stop on almost 9% more occasions on the single carriageway, and almost 6% more occasions on the dual carriageway. This overall measure of propensity to stop was balanced in the design so that the same number of observations was made at each of the trigger distances. However, one observation on the single carriageway road (at 40 m) could not be ascertained from the data: this was the final observation on the participant’s journey and the data reduction program was unable to extract it from the data file. Even taking this into account, significantly more drivers (at the 95% confidence level) decided to stop on the single carriageway when approaching a crossing at a junction. The difference was weakly significant on the dual carriageway: at the 90% confidence level.

The smaller sample sizes at individual trigger points (only two observations for each driver) resulted in the difference only being significant (at the 95% confidence level) on the single carriageway at 40 metres from the crossing, where half as many drivers stopped when approaching crossings than stopped when approaching junctions. At the other trigger points in Table 7-2, an extra 7% to 8% of all the drivers decided to stop when faced with a signal change on the approach to a junction crossing, than at a stand-alone crossing.

Drivers were therefore more cautious when approaching a crossing at a junction rather than one in the middle of a link and this made them more likely to stop.

Generally, a LOGIT model can be used to explain stopping decisions on the approach to a junction. Fitting a LOGIT model to the data provides a prediction of the proportion of drivers stopping for all trigger distances. Models have been fitted to the observed decisions on both road types and on the approach to both types of crossing; these are shown in Figure 7-4.

These models clearly show how decisions differed according to road, and crossing, type. The most marked difference is in the central section of the dilemma zone. On the single carriageway road the model predicts that 9 to 15% more drivers will stop when faced with a change of signal at 40 to 75m from the stop line if the crossing is at a junction. Similarly, it predicts that 8 to 10% more drivers
would stop under similar circumstances on a dual carriageway road when 65 to 90m from the stop line. The difference in the proportion stopping at any distance is the vertical distance between the two lines.

Of particular interest is the high degree of agreement between modelled decisions made by drivers on a single carriageway road approaching a stand-alone crossing, and those made on a dual carriageway road when approaching a junction. This implies that the stopping decisions at the two types of traffic signal installation are approximately the same when the speed limit is 10 mph (16 km/h) different. However, the difference between the observed 85th percentile of approach speeds was only 8 km/h (5 mph).

7.3 Red Running

Previous sections have shown that drivers appear to use less caution when approaching a stand-alone crossing than a junction. Such behaviour resulted in a higher proportion of drivers continuing over the stopline if the signals changed when they were in the dilemma zone. Combining these two behavioural differences it seems likely that drivers could make more poor decisions when approaching the stand-alone crossings. The incorrect decision to continue would cause the driver to pass over the crossing either close to the start of red, or red run the signals. Actual numbers of red running events and late running events (red runners and those in the last second of amber) are shown in Table 7-3 and Table 7-4 respectively. It should be remembered that the drivers in the trial were deliberately presented with a much larger number of difficult decisions than they would normally encounter in a much longer drive. The percentages in Table 7-3 do not represent typical infringements rates.

Table 7-3: Number and percentage of red running events

<table>
<thead>
<tr>
<th>Type of road</th>
<th>Stand-alone</th>
<th>Junction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single carriageway</td>
<td>19</td>
<td>5.4%</td>
</tr>
<tr>
<td>Dual carriageway</td>
<td>28</td>
<td>8.0%</td>
</tr>
</tbody>
</table>

Table 7-4: Number and percentage of late running events

<table>
<thead>
<tr>
<th>Type of road</th>
<th>Stand-alone</th>
<th>Junction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single carriageway</td>
<td>88</td>
<td>25.2%</td>
</tr>
<tr>
<td>Dual carriageway</td>
<td>71</td>
<td>20.3%</td>
</tr>
</tbody>
</table>

Fewer drivers passed over the stop line late into the amber, or ran the red, at junctions than at stand-alone crossings. The percentage difference for late running events was significant (at the 95% confidence level) on the single carriageway, whilst the percentage difference in red runners was significantly different on the dual carriageway.

Drivers on the single carriageway road who passed over the stop line in the last second of amber were 60 or less metres from it at the change to amber. These decisions were made in the mid section of the dilemma zone, where drivers would be expected to have the most hesitancy and need to make difficult decisions.

Drivers observing the change to amber at distances less than 70 metres on the dual carriageway were able to pass over the crossing only slightly into the amber period owing to their approach speed. However, at greater distances it is possible their higher approach speeds caused them to decide to cross the stand-alone crossings into the red phase.
The number of events where a driver passed the stop line within the last second of the amber phase, together with the difference in the number of drivers at the two types of signal installation, is shown in Figure 7-5.

![Crossing in last second of amber](image)

**Figure 7-5: Drivers crossing in the last second of amber on the single carriageway road**

Most of the events when the driver just made it across the crossing within the amber period were at most 60 metres from the crossing when the signals changed.

A linear relationship appears to exist between the difference in the number of drivers passing over the stop line within the last second of amber at the two types of crossing and the distance from the stop line at amber onset. Close to the stop line drivers were more likely to decide to continue over a stand-alone crossing, than a junction, even though it entailed reaching the stop line at the end of the amber phase.

The speeds drivers were travelling at when they passed over the stop line are shown in Figure 7-6. Interestingly, red runners were travelling slightly slower than drivers passing over the stop line late into the amber phase. However, the average speed at the stop line when crossing either late in the amber phase, or in the red phase, was higher than that of drivers who continued through over the stop line without encountering a signal change: approximately 76 km/h on a single carriageway and 83 km/h on a dual carriageway. Figure 7-7 examines the speed profile of drivers who subsequently ran the red.
Figure 7-6: Speeds used when passing over the stopline

Figure 7-7: Approach profiles of red runners
A different decision making process appears to be used when deciding to run the red compared with continuing owing to the signals not changing. When the signals do not change drivers generally increase their speed through the junction (see Figure 7-2). However, when running a red, drivers continued to reduce their speed up to the stop line, and then start to accelerate back up to their cruise speed. When comparing the detailed shapes of the lines in Figure 7-7 it should be remembered that there are relatively few events in each category. However, there is an indication that these drivers travelled at higher than average speeds during their approach to the stop line: for example on the approach to a junction on a dual-carriageway their average speed was 8 to 15 km/h (5 to 9 mph) above the average for all drivers in the last 100 metres.

Overall those who crossed late into the amber phase, or ran the red, appear to be drivers who approached with less caution than the norm. Furthermore, when these drivers decided to continue they tended to slow down on their final approach, implying a poor decision. Such behaviour is more likely to place the driver in conflict with pedestrians, than the more controlled overall speed profiles found when the signals did not change. The less cautious behaviour was more prevalent at stand-alone crossings, rather than at junctions. Hence, it would be expected that junctions are safer than signal controlled crossings in the middle of a link.

### 7.4 Maximum Decelerations

The deceleration used when stopping is another measure of the caution used by drivers. Drivers who approach faster with less consideration for stopping will need to use a higher deceleration rate in order to stop. Alternatively, a higher deceleration is indicative that the driver is more willing to stop, accepting the discomfort associated with it. Average maximum rates used by drivers stopping are shown in Figure 7-8, and the distance at which they used their maximum deceleration is shown in Figure 7-9.

![Maximum deceleration used by drivers stopping](image)

**Figure 7-8: Maximum deceleration rates used by drivers stopping**

The profiles of maximum deceleration rates that drivers found acceptable are remarkably similar when the same type of traffic signal installation is encountered. The difference between the profiles
on the single and dual carriageway show the higher deceleration rate required to stop owing to the
greater approach speeds used within the 70 mph (113 km/h) limit.

Profiles associated with stand-alone and junction crossings imply that two different mechanisms are
probably involved in determining the deceleration rates used. At distances greater than 60 metres
from the stop line, drivers deciding to stop when approaching a junction used lower rates of
deceleration than under the same conditions at a stand-alone crossing. Figure 7-2 confirms that the
average approach speed observed at these distances was greater at the crossings located within the
middle of a link, and hence a higher rate of deceleration would generally be required to stop.

Closer to the stop line than 60 metres the approach speed profiles start to converge for observations
within the same speed limit (or on the same type of road). At these distances drivers accepted higher
rates of deceleration if stopping on the approach to a junction, than a stand-alone crossing. The
increase was significant at the 95% confidence limit on the single carriageway road, and at the 90%
confidence limit on the dual carriageway road. This again emphasises that drivers were more willing
to stop on the approach to a junction than at a crossing in the middle of a link. There were very few
stopping events at the shortest trigger distances. Only those approaching most slowly were prepared
to stop at stand-alone crossings at the shortest trigger distance and they did not have to brake as hard
as faster drivers who stopped at junctions.

![Distance travelled before maximum deceleration for drivers stopping](image)

Figure 7-9: Distance when maximum deceleration applied

The distance travelled between the start of amber and the maximum rate of deceleration effectively
measures a combination of driver reaction time, time to apply the brake pressure and the emphasis
they place on the decision. Figure 7-9 shows that this depends on the distance of the trigger point from
the stop line and the type of crossing, and not the speed limit on the road.

The distance covered before reaching maximum deceleration appears to be linearly correlated to the
distance from the stop line when the signals changed. When close to the stop line it took slightly over
20 metres to decide to stop and then apply the maximum deceleration, and the average time to reach
this deceleration was less than 2 seconds. Further from the stop line reactions were more measured
and the average time to reach the maximum deceleration was up to 4 seconds.
In addition, greater distances were covered before reaching maximum deceleration when drivers stopped at junctions, than when they stopped at stand-alone crossings; another indicator that the decisions were more measured when approaching a junction. It is possible the extra caution shown by drivers when approaching a junction resulted in extra time to make the decision to stop.

7.5 Reaction Time

Time to reach the maximum rate of deceleration includes the reaction time. This is the time between the signals changing and the driver first applying pressure to the brake pedal. Occasions where the driver was already braking before the signals changed were excluded from this analysis. The observed reaction times according to distance from the stop line when the signals changed is shown in Figure 7-10.

![Graph of Reaction Times if Stopping](image)

**Figure 7-10: Reaction times of those drivers choosing to stop**

In agreement with the time to reach maximum deceleration, reaction times generally decreased with distance from the stop line. In addition, all reaction times were less than one second, implying that the drivers were alert during their approach to the crossing.

Close to the stop line, reaction times were less at stand-alone crossings than those at junctions. Evidence in earlier sections shows less caution was used on approaching stand-alone crossings. This implied that the decisions were more measured, and therefore controlled, when approaching crossings at junctions.

At the shortest trigger distances almost all the drivers who stopped were already braking when the signals changed to amber. Consequently there are no reaction times recorded at the shortest trigger distances except on the dual carriageway approaching a junction.
8 Driver types

Drivers approached the traffic signals at a wide range of speeds. Some travelled at 60 km/h (37 mph), whilst others were at 120 km/h (75 mph) when 160 metres from the stop line, see Figure 7-1. Section 7 indicated that drivers who approached with the most caution generally also decreased their speed as they approached closer to the signals. Further, decreasing their speed would be expected to influence their decision of whether to stop or continue when the signals changed. This section examines the effect of approach speed, or driver type, on decision making and whether drivers considered their decisions were correct.

Two sample sub-groups were formed: slower and faster drivers. These each consisted of half the sample with drivers categorised according to their average speed 160 metres from the stop line.

8.1 Approach speeds

Approach speed is a good indicator of the amount of caution drivers’ show when approaching the crossings. It has also been shown that a higher speed approach is associated with harder decisions and that more of the choices were incorrect. The approach speed profiles of faster and slower drivers are shown in Figure 8-1 and Figure 8-2.
The shape of the profiles is the same for both slower and faster drivers, both reduce their speed within the dilemma zone, then accelerate close to the crossing, when they have made their decision to continue. Slower drivers averaged in the region of 15 km/h (9 mph) less than the faster drivers on the single carriageway road and approximately 20 km/h (12 mph) less on the dual carriageway.

Both faster and slower drivers approached stand-alone crossings faster than those at a junction. This consistency between the sub-samples implies that there is a distinct behavioural difference in how all drivers approach the two types of crossing.

8.2 Stopping Decisions

The difference in approach speeds between the two types of drivers would be expected to have an effect on the number of the drivers deciding to stop. At higher speeds it is more likely that a driver encountering a change to amber will continue across the crossing, as they are more likely to be able to cross the stop line within the amber period and would need to apply a higher deceleration rate to stop. The actual decisions of both types of driver were fitted to a LOGIT model and the resulting decision curves are shown in Figure 8-3 and Figure 8-4.
As expected, faster drivers are less likely to stop at any given distance from the stop line. For example, when the signals changed at 70 metres from the junction’s stop line on a dual carriageway road 76% of the slower drivers decided to stop, whilst only 44% of the faster drivers stopped.

However, the same pattern of decisions is evident in both sub-samples. Drivers in both were more likely to stop at signals at a junction than at a stand-alone crossing. Also, the chance of a driver stopping at a stand-alone crossing on a single carriageway road (60 mph or 97 km/h) is almost the same as that of them stopping at a junction on a dual carriageway road (70 mph or 113 km/h).

### 8.3 Red Running

Higher approach speeds indicate less caution being used on the approach to the traffic signals. This has been shown to affect the probability that the drivers will decide to stop, and it would also be expected to increase the chance of a poor decision. That is, it could increase the chance that the driver will run the red, or only reach the stopline in the last second of the amber phase. The actual number of drivers reaching the stop line 2 seconds or more after the start of amber, and the number that continued after the signals had turned red are shown in Table 8-1 and Table 8-2 respectively.

#### Table 8-1: Percentage of late runners

<table>
<thead>
<tr>
<th>Type of road</th>
<th>Slower Drivers</th>
<th>Faster Drivers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stand-alone</td>
<td>Junction</td>
</tr>
<tr>
<td>Single carriageway</td>
<td>20.0%</td>
<td>14.1%</td>
</tr>
<tr>
<td>Dual carriageway</td>
<td>17.1%</td>
<td>14.7%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type of road</th>
<th>Slower Drivers</th>
<th>Faster Drivers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stand-alone</td>
<td>Junction</td>
</tr>
<tr>
<td>Single carriageway</td>
<td>30.2%</td>
<td>23.3%</td>
</tr>
<tr>
<td>Dual carriageway</td>
<td>23.3%</td>
<td>19.4%</td>
</tr>
</tbody>
</table>

#### Table 8-2: Percentage of red runners

<table>
<thead>
<tr>
<th>Type of road</th>
<th>Slower Drivers</th>
<th>Faster Drivers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stand-alone</td>
<td>Junction</td>
</tr>
<tr>
<td>Single carriageway</td>
<td>6.5%</td>
<td>3.5%</td>
</tr>
<tr>
<td>Dual carriageway</td>
<td>7.6%</td>
<td>2.9%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type of road</th>
<th>Slower Drivers</th>
<th>Faster Drivers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stand-alone</td>
<td>Junction</td>
</tr>
<tr>
<td>Single carriageway</td>
<td>4.5%</td>
<td>4.4%</td>
</tr>
<tr>
<td>Dual carriageway</td>
<td>8.3%</td>
<td>5.6%</td>
</tr>
</tbody>
</table>

Generally, a significantly greater percentage (at the 95% confidence level) of faster drivers than slower drivers passed over the stop line 2 or more seconds after the start of amber. In addition, they were more likely to run the red at junctions on dual carriageways where their approach speeds were significantly greater than those of the slower drivers. Slower drivers were slightly more likely to make poor decisions when approaching stand-alone crossings on single carriageway roads than were faster drivers, however, this difference was not statistically significant.

### 8.4 Deceleration Rates

Large differences in approach speeds should affect the deceleration used when the drivers decide to stop. It would be expected that at slower speeds the maximum deceleration rate would be less, particularly at greater distances from the stop line, as the driver can slow down in a more controlled manner. The average maximum deceleration rates used by both types of drivers on approaching the crossings are shown in Figure 8-5 and Figure 8-6.
Figure 8-5: Maximum rates of deceleration (Slower Drivers)

Figure 8-6: Maximum rates of deceleration (Faster Drivers)
Slower drivers were able to use only moderate braking in order to stop when the lights changed at distances greater than 70 metres. Closer to the stop line they needed to use high deceleration rates to stop.

Faster drivers were more likely to continue over the crossing: across all changes to amber 51% of faster driver, and 73% of slower drivers, stopped. Those that did chose to stop when the signals changed at 60 metres or more from the stop line used much higher maximum decelerations than the slower drivers.

8.5 Happy With Decision

Previous sections have shown that the faster drivers were less likely to stop when the signals changed, more likely to make a poor decision and run the red, and if they did decide to stop they needed to apply much higher rates of deceleration. Overall, the slower drivers had the extra time to make a more considered decision and react correctly to any signal changes.

After completing the simulator trial the participants were asked to complete a short questionnaire, see next section for full analysis. One of the questions asked was, whether they were happy with the decisions they had made during their journeys on the simulator. A summary of their answers according to the type of driver is shown in Table 8-3.

<table>
<thead>
<tr>
<th>Happy With Decision</th>
<th>Slower Drivers</th>
<th>Faster Drivers</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>18%</td>
<td>72%</td>
</tr>
<tr>
<td>Yes</td>
<td>82%</td>
<td>28%</td>
</tr>
</tbody>
</table>

Slower drivers were much more content with the decisions they had made, whilst the lack of caution used by the faster drivers resulted in more concern over the resulting actions they had taken.
9 Questionnaire analysis

After their second drive, participants were asked to fill in a questionnaire, reproduced in the Appendix. The purpose of the questionnaire was to explore participants’ attitudes to signal controlled, stand-alone crossings and junctions and to enquire about differences between their normal driving and the “drives” in the simulator. Most drivers (77%) said that they approached the junctions and crossings as they would in real life. Two thirds of those who did not approach them as normal made some comment that they felt the simulator car was different from their own or that they were not as confident as when driving their own car. Only 14% of the drivers who approached the traffic signals as normal made similar comments. The questionnaire responses did not suggest that any observed differences in responses to junctions and stand-alone crossings in the simulator would be unrepresentative of normal behaviour.

9.1 Cruising speed

The drivers did not have a good idea of the speed limit on the roads. The single carriageway had mandatory 60 mph signs (larger than real-life repeater signs for clarity) throughout its length. There were no speed limits signs on the dual carriageway and no street lights to imply a limit. Despite the speed limit signs on the single carriageway only half the drivers reported the speed limit as 60 mph, Table 9-1gives the details. As shown in Table 9-2, however, the drivers’ estimated speeds during the drives were mostly much nearer the speeds for which the test had been designed than might be assumed from their opinions of the speed limit. It is interesting to note the tendency to underestimate the speed at which they drove on the single carriageway; estimated speeds on the dual carriageway were more accurate.

<table>
<thead>
<tr>
<th>Perceived speed limit (mph)</th>
<th>Single carriageway</th>
<th>Dual carriageway</th>
</tr>
</thead>
<tbody>
<tr>
<td>70</td>
<td>0</td>
<td>43%</td>
</tr>
<tr>
<td>60</td>
<td>50%</td>
<td>40%</td>
</tr>
<tr>
<td>50</td>
<td>15%</td>
<td>10%</td>
</tr>
<tr>
<td>40</td>
<td>23%</td>
<td>5%</td>
</tr>
<tr>
<td>30</td>
<td>12%</td>
<td>2%</td>
</tr>
</tbody>
</table>

Table 9-2:. Participants estimated and actual cruising speed (proportion of participants)

<table>
<thead>
<tr>
<th>Speed (mph)</th>
<th>Single carriageway</th>
<th>Dual carriageway</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Estimated</td>
<td>Actual</td>
</tr>
<tr>
<td>&gt; 60</td>
<td>18%</td>
<td>44%</td>
</tr>
<tr>
<td>&gt; 50 and ≤ 60</td>
<td>45%</td>
<td>42%</td>
</tr>
<tr>
<td>&gt; 40 and ≤ 50</td>
<td>25%</td>
<td>14%</td>
</tr>
</tbody>
</table>

9.2 Caution approaching traffic signals

Most people said that the presence of pedestrians waiting at a junction or crossing affected their approach in normal driving. Rather more of the drivers (95%) are sensitive to the presence of waiting pedestrians at stand-alone crossings than at junctions (82%). Waiting pedestrians were present at all crossings and junctions during the drives on the simulator. Presumably approach speeds would have
been higher if they had not been there. Drivers were asked whether they had approached the two types of signals (junctions and stand-alone pedestrian crossings) differently, but the questions were not always interpreted well.

Of those who gave consistent answers, 13 drivers showed more caution approaching junctions than stand-alone crossings and 6 reported more caution approaching stand-alone crossings. When asked about slowing down the difference was less marked, 8 slowing more for junctions and 6 more for stand-alone crossings. Six people reported showing both more caution and slowing down more approaching junctions than stand-alone crossings, whilst 3 people reported both more caution and slowing more approaching stand-alone crossings than junctions. Overall there is an indication that the drivers believed that they approached junctions in a way that made them somewhat more prepared to stop than when they approached stand-alone crossings.

It was not possible in a simple questionnaire to explore the reasons for any difference in approach to junctions and stand-alone crossings. Possible explanations include:

- It is often possible to see all the potential hazards, pedestrians etc. at a stand-alone crossing, but it is not possible to see what is lurking round the corner at a junction
- The advance direction signing at junctions provides extra stimulus that there is a hazard ahead
- In general, the probability of having to stop at a junction is greater than at a stand-alone crossing, however, there were pedestrians waiting at all crossings and junctions in the simulator study, which considerably increases the probability of the signals changing against the driver at a stand-alone crossing.

9.3 Stopping decisions

Each driver experienced the same number of trigger points at each distance from the stopline when approaching junctions as when approaching stand-alone crossings. They were asked whether they were ever unsure of whether to stop on the approaches. Half said that they were unsure on the approach to some junctions, but rather more, 63% were unsure on the approach to stand-alone crossings. This greater unhappiness at stand-alone crossings is consistent with a more cautious approach to junctions than to crossings as concluded from the analysis of driving behaviour above.

Drivers were also asked whether they had found it hard to make decisions that they were happy with. Twenty per cent reported difficulty with some decisions on the single carriageway and 28% on the dual carriageway. When asked in terms of junctions and stand-alone crossings there was no difference between the types of signal 35% reported difficulty making at least one decision at a junction and the same proportion at a stand-alone crossing. Many of these, 28% of the total, had difficulty at both junctions and stand-alone crossings. Overall a considerable number of drivers had difficulty making decisions at some times, but the majority 55% reported not having difficulty making a decision that they were happy with at any time during the two drives. Of these drivers, the majority were female (60%). As noted in the previous section the drivers who approached with more caution, at a lower speed were much more likely to be happy that they had made the right decision than were the faster drivers.
10 Summary and discussion of simulator trial

TRL’s car simulator was successfully used in this study to investigate how drivers approached two types of traffic signal installation that can provide pedestrian crossing facilities. The signals were either situated at a stand-alone crossing, a Puffin crossing rather than a Pelican was simulated, or at a junction. This research was designed to measure key variables that underlie the behaviour of drivers on the approach to traffic signals where pedestrians may cross the road. For example, drivers showing greater caution on approaching a potential hazard would be expected to reduce their speed.

Each driver took part in two simulated journeys, one on a single carriageway road (60 mph or 97 km/h limit) and the other on a dual carriageway road (70 mph or 113 km/h limit). During each journey they encountered twelve of each of the two types of traffic signal installation and the signals changed when they approached eight of each type. The trigger distance, the distance of the car in advance of the stopline when the signals changed from green to amber varied from signal to signal. The experiment was developed so that the trigger points and type of situations faced by each driver were the same. However, the order in which they were presented to each driver varied used a randomised design that was balanced to avoid bias owing to fatigue.

Direct comparison of driver behaviour indicated that there were significant behavioural differences in the caution applied by drivers when approaching the two types of signal installation. These included:

- Drivers approached junctions at slower speeds than stand-alone crossings. The difference in the 85th percentile of approach speed was approximately 4 km/h.
- Drivers were more likely to stop when the signals changed on the approach to a junction than on the approach to a stand-alone signal controlled crossing: they stopped on 6 to 9% more of the total occasions. In particular, drivers were more likely to stop when the signals changed close to the stop line at a junction.
- LOGIT curves fitted to the stopping decisions confirmed that drivers were more likely to stop on the approach to a junction. In addition, they implied that the caution (or willingness to stop) was the same when approaching a stand-alone crossing in a 60 mph (97 km/h) limit and a junction in a 70 mph (113km/h) limit. The 85th percentiles of speed at 160 metres before the stopline were 101 km/h at the stand-alone crossing and 109 km/h at the junction crossing, implying an 8 km/h (5 mph) difference.
- Drivers were more likely to cross in the last second of amber or run the red when the signals changed on the approach to a stand-alone crossing than on the approach to a junction.
- Drivers used more controlled braking in stopping decisions at junctions than at stand-alone crossings, when the signals changed at over 60 metres from the stop line. At closer distances they were willing to accept higher deceleration rates in order to stop at a junction than at a stand-alone crossing.

Over the whole sample there were distinct differences in driver behaviour. However, as a typical cross-section of the population it included a range of drivers. The sample was therefore split into the most, and the least, cautious drivers: determined by their average approach speed. Differences did exist between these two groups of drivers. The more cautious drivers were more likely to stop, generally less likely to cross the stop line more than 2 seconds after the change to amber and use more controlled decelerations when stopping. This difference in behaviour on the approach resulted in a significantly higher percentage of the more cautious (or slower driver) being happy with the decisions that they made on whether to stop or continue through the signals when they changed to amber.

Even with these differences between the two groups of drivers, both were found to react consistently differently to the stand-alone crossings and the junctions. In particular, both groups slowed down more on the approach to a junction, were more likely to stop at the junctions and were less likely to cross more than 2 seconds after the start of amber. The only difference between the overall findings and those for the two groups was with respect to the deceleration rates used by the less cautious
drivers. As these drivers approached the stop line faster than the others the deceleration rates required to stop were fairly uniform and high at all observed trigger points.

The drivers were asked to fill in a questionnaire after completing their drives. The aim of the questionnaire was to explore participants’ attitudes to signal controlled, stand-alone crossings and junctions and to enquire about differences between their normal driving and the “drives” in the simulator. Results from the questionnaire confirmed the suitability of the simulator for the trial and that the participants tend to approach signal controlled junctions with more caution than stand-alone signal controlled pedestrian crossings.

Consequently, this study has confirmed that drivers show more caution when approaching a signal controlled junction, than approaching a stand-alone signal controlled pedestrian crossing. From a safety point of view this implies that pedestrians are safer on junction crossings than stand-alone crossings within the same speed limit. Hence, a difference in the speed criteria used when deciding suitable sites for these crossings is required. However, the suitability of the current 15 mph (24 km/h) difference in the 85th percentile of approach speed coupled with the different wording of the advice cannot be fully confirmed from this study of only 40 drivers.

The study indicated that drivers were equally likely to stop on the approach to a stand-alone crossing and a junction crossing when their 85th percentiles of approach speeds are 5 mph (8 km/h) different. However, this difference was observed under simulated conditions, which although very realistic, are known to result in drivers driving somewhat faster than on the real road. In additions drivers were more likely to meet a signal change than in reality. They could therefore have been more alert and cautious than they would under normal driving conditions.

This study was not able to explore the reasons for the observed differences in drivers’ behaviour when approaching the different types of traffic signal installation. It would be possible to use the driving simulator to study the effect of signs and the visual impact of junctions and stand-alone crossings on drivers’ behaviour. The lessons learnt could then be applied to real installations to try to reduce accidents. It would, however, require a large study to produce reliable results.
11 Accident analysis

The third strand of the project was to investigate the accident record at the sites where pedestrian behaviour had been studied. It was acknowledged that with a small sample of sites it would be difficult to draw any firm conclusions, but the STATS19 data for the sites were studied for indications of significant factors.

Accident data were analysed for the sites at Ferring, Birmingham, Nottingham and Leicester from 1st July 2000 to 31st December 2003. The crossings at Uttoxeter and Towcester were installed more recently than the other sites and so the analysis period started later, shortly after installation, 1st August 2002 for Uttoxeter and 1st April 2003 for Towcester. Detailed figures for the pedestrian demand at the junctions are not available as the observations of pedestrian behaviour were limited to one arm of each junction. On average, approximately half as many people crossed the road on one arm of the junction as at the nearby stand-alone crossing. Therefore, it is expected that the pedestrian demand at the junctions and stand-alone crossings were similar overall.

All accidents within 50m of the crossing or junction were included. There were not many accidents and casualties at each site and therefore the casualties for all of the sites have been combined. The casualties and accident types are described in the following sections and summarised in Table 11-1.

11.1 Pedestrian casualties

There were four pedestrian casualties at the junction sites, one fatal, two serious and one slight giving a killed and seriously injured ratio of 3/4 (0.75). The pedestrians included a 14 year old child, a 60 year old and the other two were adults under 60 years old. One pedestrian was on the crossing and three were within 50 metres of the crossing. Two of the pedestrians were crossing from the drivers’ nearside, one was crossing from the drivers nearside masked by a parked or stationary vehicle and one (the fatal accident which involved a 32 year old) was crossing from the drivers offside masked by a parked or stationary vehicle.

At the pedestrian crossing sites there were 3 casualties which consisted of one serious and two slight casualties giving a killed and seriously injured ratio of 1/3 (0.33). The pedestrians were all adults below 60 years old and all were on the crossing. One was crossing from the drivers offside masked by a parked or stationary vehicle, one was crossing from the drivers offside and one was crossing from the drivers nearside.

11.2 Cyclist casualties

There were two slight cyclist casualties at the junction sites. The cyclists were 27 and 55 years old. The accidents involved a car and an ‘other motor vehicle’. It is not possible from the accident record to say whether the cyclist was attempting to cross the road using the pedestrian crossing facility.

At the pedestrian crossing sites there was one slight casualty. The injured cyclist was 16 years old and the accident involved an ‘other motor vehicle’. For accidents at pedestrian crossings (defined as within 20m of the crossing), STATS19 records whether pedestrians were using the crossing. There is no equivalent information for cyclists. The accident record listed both cyclist and vehicle as turning left. Therefore, it is unlikely that the cyclist was using the crossing.

11.3 Motorcyclist casualties

There were no motorcyclist casualties at the junction sites.

At the pedestrian crossing sites there was a 36 year old motorcyclist who was seriously injured in a collision with a car.
11.4 Car occupant casualties

Car occupants were the most common casualties. Of the total casualties 80% at junctions and 65% at pedestrian crossing sites were car occupants. It is not surprising that car occupants were the most common casualties at junctions, where the traffic signals are installed principally because of the conflicts between vehicle movements. The high proportion of car occupant casualties at the stand-alone crossings is possibly more surprising and indicates the potential for vehicles to collide at traffic signals even when travelling in the same direction on the same link. The next highest category was pedestrian casualties with 12% of total casualties at junctions and 18% at stand-alone crossings.

11.5 All casualties

There were a total of 33 casualties at the junction sites which consisted of one fatal, four serious and 28 slight giving a killed and seriously injured ratio of 5/33 (0.15).

At the pedestrian crossing sites there were 17 casualties which consisted of two serious and 15 slight giving a killed and seriously injured ratio of 2/17 (0.12).

The difference in numbers of total casualties at the junctions and pedestrian crossing sites is due to the greater opportunities for vehicle-vehicle collisions at junctions and should not be taken to indicate that less strict criteria should be used for the installation of stand-alone crossings than for signals at junctions on high-speed roads. For the purpose of this study, the pedestrian and cyclist casualties are more important than the total number of casualties.

Over 80% of the casualties at the junction sites and over 90% at the pedestrian crossing sites were in the age range 16 to 59 years old inclusive.

11.6 Accident types

At the junction sites the majority of accidents were car/car accidents which accounted for 66%, pedestrian/car accounted for 15% and car/goods vehicles also accounted for 15%. Thus 26 of the 27 accidents involved at least one car. The types of accidents at the pedestrian crossing sites were more varied with only car/car and pedestrian/car accidents accounting for two accidents each. The remainder were single accidents of different types e.g. pedestrian/LGV (Large Goods Vehicle), car/LGV, cyclist/other motor vehicle, car only, car/motorcycle, car/LGV, car/minibus and LGV/LGV. Thus at least one car was involved in 9 of the 12 accidents at pedestrian crossings.

11.7 Effect of alcohol

It was reported that three drivers gave positive breath tests. These were all at the junction sites and all were car drivers.

11.8 Effect of weather

At the junction sites 19 out of 23 accidents (83%) were in fine weather and 4 (17%) were in rain, snow, fog or mist. The weather at 4 junction accidents was unknown. The corresponding values for pedestrian crossing sites were 11 out of 12 (92%) in fine weather and 8% in rain, snow, fog or mist.

11.9 Effect of daylight

At the junction sites 18 out of 27 accidents (67%) were in daylight and at pedestrian crossing sites there were 10 out of 12 accidents (83%) in daylight.
11.10 Signal condition
All of the automatic traffic signals were assumed to be working properly because none were described as being ‘out’ or ‘partially defective’ in any of the accident reports.

11.11 Discussion
At first sight, the severity ratio of pedestrian casualties at the junction sites appears alarmingly high at 0.75, compared with a national average at light controlled junctions of 0.24. However, with a total of only 4 accidents the severity ratio is very sensitive to the classification of a single accident. For instance, including cyclist accidents with pedestrian accidents would reduce the severity ratio to 0.5. The same qualification is needed for the severity ratio at the stand-alone pedestrian crossing sites of 0.33, which is similar to the national average of 0.25 for Pelican crossings.

It is worth noting that in 2 of the 4 pedestrian accidents at or near junctions and one of the 3 at a stand-alone crossing, the pedestrian was said to be masked from the driver’s view by a parked or stationary vehicle. The only serious conflict observed in the monitoring of the Uttoxeter and Towcester crossings occurred at Uttoxeter and also involved masking. As all the sites were dual carriageways, the possibility for masking by vehicles stopped in adjacent lanes was considerably greater than at single carriageway sites. It may be the provision of multiple lanes more than vehicle speed that increases the risk of pedestrians and cyclists accidents involving masking.

At the pedestrian crossing sites all of the pedestrians were injured on the crossing, but 3 of the pedestrians casualties “at” junctions were not on the crossing, but within 50m of it. With such small numbers it would be inadvisable to draw conclusions on whether pedestrians are more likely to cross using the formal crossing when it is stand-alone rather than at a junction. Indeed, the observations of pedestrians’ behaviour noted a few people crossing near, but not on, the stand-alone crossings, but none crossing close to the junctions (see section 3.3.4). Vehicle red times at junctions are longer on average than at stand-alone crossings leading to longer queues. Stationary queues may be seen by pedestrians as an opportunity to cross, but the possibility of masking with multiple lanes and high-speed vehicles can cause serious accidents.

For total accidents there are clear differences with more car/car accidents at junctions than stand-alone pedestrian crossings, but a large difference is to be expected due to the greater opportunity for such collisions at junctions.

All of the other variables considered were similar for the junction and the pedestrian crossing sites, see Table 11-1. Again the numbers of accidents are too small to draw conclusions.

Table 11-1: Summary of accident and casualty data

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
<th>Total at junctions</th>
<th>Total at stand-alone crossings</th>
<th>Difference in percentages, junction - stand-alone</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number</td>
<td>Percentage</td>
<td>Number</td>
<td>Percentage</td>
</tr>
<tr>
<td>Casualty Slight</td>
<td>28</td>
<td>84.8%</td>
<td>15</td>
<td>88.2%</td>
</tr>
<tr>
<td>Serious</td>
<td>4</td>
<td>12.1%</td>
<td>2</td>
<td>11.8%</td>
</tr>
<tr>
<td>Fatal</td>
<td>1</td>
<td>3.0%</td>
<td>0</td>
<td>0.0%</td>
</tr>
<tr>
<td>Category</td>
<td>Description</td>
<td>Total at junctions</td>
<td>Total at stand-alone crossings</td>
<td>Difference in percentages, junction - stand-alone</td>
</tr>
<tr>
<td>--------------</td>
<td>---------------------</td>
<td>--------------------</td>
<td>--------------------------------</td>
<td>--------------------------------------------------</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number</td>
<td>Percentage</td>
<td>Number</td>
</tr>
<tr>
<td>Casualty class</td>
<td>Pedestrian</td>
<td>4</td>
<td>12.1%</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Cyclist</td>
<td>2</td>
<td>6.1%</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>M/cyclist</td>
<td>0</td>
<td>0.0%</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Car occupant</td>
<td>26</td>
<td>78.8%</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>LGV(^{\text{ii}}) occupant</td>
<td>0</td>
<td>0.0%</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>HGV occupant</td>
<td>1</td>
<td>3.0%</td>
<td>0</td>
</tr>
<tr>
<td>Casualty age</td>
<td>0-15 years</td>
<td>1</td>
<td>3.0%</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>16-59 years</td>
<td>27</td>
<td>81.8%</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>60+ years</td>
<td>5</td>
<td>15.2%</td>
<td>1</td>
</tr>
<tr>
<td>Pedestrian location</td>
<td>On crossing</td>
<td>1</td>
<td>25.0%</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Within zigzag</td>
<td>0</td>
<td>0.0%</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>In 50m of PX</td>
<td>3</td>
<td>75.0%</td>
<td>0</td>
</tr>
<tr>
<td>Time of day</td>
<td>AM</td>
<td>8</td>
<td>29.6%</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>PM</td>
<td>19</td>
<td>70.4%</td>
<td>10</td>
</tr>
<tr>
<td>Day</td>
<td>Weekday</td>
<td>17</td>
<td>63.0%</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Weekend</td>
<td>10</td>
<td>37.0%</td>
<td>3</td>
</tr>
<tr>
<td>Month</td>
<td>Apr-Sep</td>
<td>10</td>
<td>37.0%</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Oct-Mar</td>
<td>17</td>
<td>63.0%</td>
<td>6</td>
</tr>
<tr>
<td>Light</td>
<td>Light</td>
<td>18</td>
<td>66.7%</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Dark</td>
<td>9</td>
<td>33.3%</td>
<td>2</td>
</tr>
<tr>
<td>Weather</td>
<td>Fine</td>
<td>19</td>
<td>70.4%</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>Rain/fog/mist</td>
<td>4</td>
<td>14.8%</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Other/unknown</td>
<td>4</td>
<td>14.8%</td>
<td>0</td>
</tr>
<tr>
<td>Driver breath</td>
<td>Positive</td>
<td>3</td>
<td>5.8%</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Negative</td>
<td>20</td>
<td>38.5%</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>29</td>
<td>55.8%</td>
<td>12</td>
</tr>
</tbody>
</table>

\(^{\text{ii}}\) LGV = Light Goods Vehicle, HGV = Heavy Goods Vehicle
<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
<th>Total at junctions</th>
<th>Total at stand-alone crossings</th>
<th>Difference in percentages, junction - stand-alone</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Number</td>
<td>Percentage</td>
<td>Number</td>
</tr>
<tr>
<td>Accident type</td>
<td>Ped.-Car</td>
<td>4</td>
<td>14.8%</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Ped.-LGV</td>
<td>0</td>
<td>0.0%</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Cycle-Other</td>
<td>1</td>
<td>3.7%</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Cycle-car</td>
<td>1</td>
<td>3.7%</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Car-Car</td>
<td>17</td>
<td>63.0%</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Car only</td>
<td>0</td>
<td>0.0%</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Car-M/cycle</td>
<td>0</td>
<td>0.0%</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Car-LGV</td>
<td>1</td>
<td>3.7%</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Car-HGV</td>
<td>3</td>
<td>11.1%</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Car-minibus</td>
<td>0</td>
<td>0.0%</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>LGV-LGV</td>
<td>0</td>
<td>0.0%</td>
<td>1</td>
</tr>
</tbody>
</table>

11.12 Conclusions

It is not possible to draw any firm conclusions from such a small sample. Overall there is no clear evidence of a difference in pedestrian casualty risk at stand-alone crossings and signal controlled junctions. However, the severity ratio, particularly for the pedestrian junction casualties, does reinforce the potential danger to pedestrians from faster moving vehicles.
12 **Summary and conclusions**

The objective of the study was to review the guidelines for the provision of signal controlled crossings on high-speed roads. In particular, should there be different guidelines for the provision of stand-alone crossings (Puffins, Pelicans, Toucans and crossings with equestrian facilities) than for signal controlled junctions with pedestrian crossing facilities?

The study was split into three components:

- Study of pedestrians’ behaviour at a selection of signal controlled stand-alone crossings and junctions
- Study of drivers’ behaviour in the TRL driving simulator
- Investigation of accidents at the sites where pedestrian behaviour had been studied.

12.1 **On-road study of pedestrians’ behaviour**

The behaviour of cyclists crossing the road at the crossings and junctions was analysed as well as that of pedestrians using the crossings. No obviously unsafe behaviour was observed at any of the stand-alone crossings or junctions during the on-street study. There was no evidence that pedestrians and cyclists who crossed against the traffic signals chose to cross in different length gaps at junctions or at stand-alone crossings. Typically the gaps chosen meant that the person crossing had cleared the potential collision zone 6 seconds before a vehicle entered the zone. There was a slight indication of frustration due to the time waiting for an invitation to cross at the stand-alone crossing in Birmingham; pedestrians were seen to re-press the demand button, several times in some cases. The proportion crossing against the signals increased with average waiting time at both stand-alone crossings and junctions. The implication from the Nottingham sites, however, is that the probability of crossing against the signals is greater at a stand-alone crossing than at a junction with similar vehicle flows and waiting times.

12.2 **Driving simulator study of drivers’ behaviour**

Two roads were used in the simulator study of driver behaviour, a single carriageway and a dual carriageway. The experiment was designed to examine behaviour at speeds around the upper limit in the guidance for stand-alone crossings and drivers did drive in the desired speed range. Average speeds on the approach to traffic signals (160m before the stopline) were 88 km/h on the single carriageway and 93 km/h on the dual carriageway. Results from this part of the study show a difference in the behaviour of drivers approaching traffic signal controlled junctions and signal controlled stand-alone crossings on high-speed roads. All the measures of behaviour showed drivers being more cautious at the junctions than at stand-alone crossings:

- Approach speeds were lower (85th percentile 4km/h lower from 250m before the stopline) at the junctions
- Drivers were more likely to stop when the signals changed from green on their approach to a junction, particularly when the change occurred close (40 to 80m) to the stopline
- Drivers were more likely to cross the stopline in the last second of amber or to red-run at stand-alone crossings than junctions
- Drivers used more controlled braking when the signals changed from green to amber at over 60m before the stopline on the approach to a junction than on the approach to a stand-alone crossing. When the signals changed at closer distances they were willing to accept higher deceleration rates to stop at junctions than at stand-alone crossings.

These conclusions were true for the whole sample of drivers and for each group when the drivers were split into two groups: slower and faster drivers based on their average approach speeds. The only
exception was that the deceleration rates required to stop by the faster drivers were fairly uniform and high at all observed trigger points.

Results from the questionnaire filled in after the simulator drives confirmed the suitability of the simulator for the trial and that the participants tend to approach signal controlled junctions with more caution than stand-alone signal controlled pedestrian crossings.

This study was not able to explore the reasons for the observed differences in drivers’ behaviour when approaching the different types of traffic signal installation. It would be possible to use the driving simulator to study the effect of signs and the visual impact of junctions and stand-alone crossings on drivers’ behaviour. The lessons learnt could then be applied to real installations to try to reduce accidents. It would, however, require a large study to produce reliable results.

12.3 Accident study

The accident records at each of the sites studied in the first phase of the project were analysed for factors that might be particularly relevant at high-speed signal controlled sites. It was not possible to draw any firm conclusions as the number of accidents was very small. It is possible that masking of on-coming vehicles by stopped vehicles is more common at high-speed sites than lower speed ones, because of the combination of multiple lanes and the possibility of high-speeds in unobstructed lanes. Overall there was no clear evidence of a difference in pedestrian casualty risk at stand-alone crossings and signal controlled junctions. However, the severity ratio, particularly for the pedestrian junction casualties, did reinforce the potential danger to pedestrians from faster moving vehicles.

12.4 Overall

There is strong evidence from the simulator study that drivers approach traffic signalled junctions more cautiously and are more likely to stop when the signals change against them than at stand-alone crossings.

The on-road study of pedestrians showed similar behaviour at the two types of installation, except an indication of a greater propensity to cross against the signals at stand-alone crossings than at junctions. The study emphasised the need to keep pedestrian waiting times as short as possible to minimise the number of pedestrians who cross against the signals. Double-cycling UTC controlled crossings significantly reduces pedestrians’ waiting time. At the majority of the sites studied the method of operation resulted in longer delays to pedestrians at the stand-alone crossings than at junctions for those who waited for the main road vehicular traffic to be stopped. Longer waits result in increasing numbers of pedestrians crossing against the signals, providing further evidence of the need for more cautious guidelines on the installation of stand-alone crossings than signal controlled junctions.

The accident study did not identify any factors that affected accidents differently at stand-alone crossings and junctions. It did emphasise the danger to pedestrians from fast moving vehicles and the dangers of pedestrians’ view of approaching vehicles being masked by stationary vehicles.

It is considered that the results of this study, particularly the simulator trial, justifies the provision of more cautious guidelines for the installation of stand-alone, signal controlled crossings than for signal controlled junctions on high-speed roads. A much larger study would be required to thoroughly validate the exact details of the guidelines, but there is no evidence from this study of any problems with the current guidance on where to use signal controlled crossings. The operation of crossings should consider the strong desire of pedestrians for short waiting times.
Acknowledgements

The work described in this report was carried out in the Traffic Group of TRL Limited. The authors are grateful to David Bretherton who carried out the quality review and auditing of this report.

References


The following traffic notes and traffic advisory leaflets available from the Department for Transport provide relevant information on pedestrian and equestrian crossing facilities:

- LTN 1/95 Assessment of Pedestrian Crossings
- LTN 2/95 Design of Pedestrian Crossings
- TAL 4/98 Toucan Crossing Development
- TAL 1/01 Puffin Pedestrian Crossings
- TAL 1/02 The Installation of Puffin Pedestrian Crossings
- TAL 2/03 Signal-control at Junctions on High-speed Roads
- TAL 3/03 Equestrian Crossings
- TAL 5/05 Pedestrian Facilities at Signal-Controlled Junctions
Appendix A. Post simulator drive questionnaire

NAME: No:

Post simulator drive questionnaire for signal-controlled pedestrian crossings on high-speed roads

1. During the drive you encountered a number of pedestrian crossings, can you describe the two different types you encountered?

Type A: ________________________________________________

Type B: ________________________________________________

2. Did the presence of pedestrians waiting at the kerbside affect your approach to the traffic signals at junctions?

   Yes □ No □

   If yes, how? __________________________________________
   ______________________________________________________
   ______________________________________________________

3. What is the speed limit on a single carriageway similar to the one that you have just driven?

   □□ mph

4. What is the speed limit on a dual carriageway similar to the one that you have just driven?

   □□ mph

5. Did the presence of pedestrians waiting at the kerbside affect your approach to the traffic signals at stand-alone crossings?

   Yes □ No □

   If yes, how? __________________________________________
   ______________________________________________________
6. When you are driving your own car, does the presence of pedestrians at a crossing affect how you approach them? (Please tick all the appropriate boxes)

<table>
<thead>
<tr>
<th>At junction</th>
<th>Yes □</th>
<th>No □</th>
</tr>
</thead>
<tbody>
<tr>
<td>At stand alone crossing</td>
<td>Yes □</td>
<td>No □</td>
</tr>
</tbody>
</table>

If yes, how? __________________________________________
_____________________________________________________
_____________________________________________________

7. Would you say that you approached the crossings as you would in real life? (Please tick all the appropriate boxes)

<table>
<thead>
<tr>
<th>At junction</th>
<th>Yes □</th>
<th>No □</th>
</tr>
</thead>
<tbody>
<tr>
<td>At stand alone crossing</td>
<td>Yes □</td>
<td>No □</td>
</tr>
</tbody>
</table>

8. Do you think that you approached the two different types of crossings differently? (Please tick all the appropriate boxes)

- More caution when approaching junction □
- More caution when approaching stand alone crossing □
- Slowed down more when approaching junction □
- Slowed down more at stand alone crossings □
- Other (please state) __________________________ □

_____________________________________________________
_____________________________________________________

10. Some stopping decisions were purposefully placed so that it was difficult to stop. Would you say that under these conditions you were: (please tick the appropriate box)

- More likely to stop than when driving your own car □
- Less likely to stop than when driving your own car □
- Same as usual □

If NOT “Same as usual” Why?

_____________________________________________________
_____________________________________________________
11. Were there any instances when approaching junctions where you were unsure whether to stop at the traffic lights or to carry on driving? (Please tick all the appropriate boxes)
   - At junction   Yes □ No □
   - At stand alone crossing   Yes □ No □

12. During your drive approximately what speed do you think you were travelling at between the crossings, on the single carriageway road?
   [ ] mph

13. During your drive approximately what speed do you think you were travelling at between the crossings, on the dual carriageway road?
   [ ] mph

14. Did you find it hard to make decisions that you were happy with at the: (please tick appropriate box)
   - single carriageway roads   Yes □ No □
   - dual carriageway roads   Yes □ No □

15. Did you find it hard to make decisions that you were happy with at the: (please tick the appropriate box)
   - Junctions   Yes □ No □
   - Stand alone crossings   Yes □ No □