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Low Level Cycle Signals used as repeaters of the main traffic signals

Track trial report

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Contents

Appendices

Figures

Tables

Glossary of abbreviations

ASL	Advanced Stop Line (see Section 1.2.2)
LLCS	Low Level Cycle Signals (see Figure 1)
SRS	Small Road System test track facility at TRL
TP	Timing Point

Executive summary

This report summarises the results from the first sub-trial of a larger track trial investigating the reactions of road users to Low Level Cycle Signals (LLCS) under different junction configurations. These findings are focussed on how road users (cyclists, car drivers, motorcyclists, HGV drivers and pedestrians) responded to them as repeaters for standard traffic signals on the same pole; that is they changed at the same time as the main signals.

The trials were conducted at a specially constructed typical “urban” four-arm junction built at TRL’s test track. The trial consisted of a “control” and “treatment” experiment, with the LLCS covered and uncovered to understand the relative effect of the signals on behaviour. Trials were conducted over ten days, with a total of 248 participants: cyclists (3½ days); car drivers (2 days); motorcyclists (1 day); HGV drivers (1 day); pedestrians (1 day) and partially sighted pedestrians (1 day).

Key findings are listed at the end of each sub-section and are referenced here in square brackets. In summary:

1. Generally, the LLCS were well understood (75% to 95% across the different road user groups) [F1.a]. There was only a minor concern that a small percentage of pedestrians, cyclists and car drivers interpreted them as pedestrian crossing signals, potentially as Toucan crossing signals [F1.b]. All the partially sighted pedestrians understood that they were not for them [F1.c].
2. Most road users (at least 80%) considered that cyclists would benefit from LLCS [F2.a]. About 80% of cyclists were in favour of them, and over 90% of most other road user groups (excluding motorcyclists) were not negative towards them [F2.b].
3. Suggestions for improvements included to make the signals bigger and more obvious and also to provide an early release [F2.c]; about three-quarters of the cyclists said that the height and angle was ‘about right’ [F2.d].
4. Most cyclists used them as an extra source of information [F3.a]; in particular whilst they typically used the main signals on their approach to the junction, 70 to 80% of cyclists used the LLCS whilst waiting to turn left [F3.a]. At the uncontrolled crossing, about half of the pedestrians said that they used the LLCS, with approximately 10% stating they were the most important factor when deciding to cross [F3.b].
5. The LLCS did not adversely affect compliance at the junction. There was a slight reduction in the percentage of cyclists who went through the junction on a red signal [F4.a]. The stopping position of participants was largely unaffected, although there were some small variations in some scenarios [F4.b], [F4.c]. The times car drivers and cyclists started moving and entered the junction were also unaffected [F5.a].
6. No cyclists said that junction felt more unsafe with the LLCS and about half said the junction was either safer or much safer [F6.a]; LLCS were perceived to provide clearer information at a convenient height, made some cyclists feel more confident, while others suggested that LLCS may make drivers more aware of cyclists [F6.b].

7. About a quarter of motorcyclists and a quarter of car drivers said the safety impacts were positive, with some saying that they found the extra information useful, while others said it made them more aware of cyclists. A similar proportion of motorcyclists and car drivers said there were negative impacts on safety due to the LLCS, giving reasons including confusion, distraction, too much information and the potential for other road users using the signals. Most pedestrians thought that LLCS had no effect on them, and none said that the junction was more unsafe [F6.c], [F6.d].

The evidence from this trial supports the progression to on-street trialling of LLCS as repeaters on the same poles as the main traffic signals. The evidence suggests that the system would be quickly understood by nearly all road users, would not adversely affect safety and could offer a benefit to cyclists as a convenient source of information. The only caveat is that a small number of pedestrians misinterpreted the meaning of the signals to be for cyclists crossing the road. It is probable that pedestrians would correctly interpret them in the context of on-street applications; however, some monitoring of behaviour to confirm this would be advisable.

1 Introduction

This report summarises the results from the first sub-trial of a larger trial investigating the reactions of road users to Low Level Cycle Signals (LLCS) under different junction configurations. These findings are focussed on how road users (cyclists, car drivers, motorcyclists, HGV drivers and pedestrians) responded to them as repeaters for standard traffic signals on the same pole; that is they changed at the same time as the main signals.

This document is structured as follows:

- Section 2 summarises the methodology of the trial.
- Section 3 presents the findings to six key research questions.
- Section 4 summarises the findings and considers how they relate to the study objectives.

A consistent colour scheme is used in the graphs in this report as shown in Table 1.

	Cyclists		Red / *Red Man*
	Car drivers		Red & Amber
	Motorcyclists		Green / *Green Man*
	HGV drivers		Amber
	Pedestrians		*Blackout*

Table 1 – Colour scheme for graphs

1.1 Scope and relation to other trials

The Low Level Cycle Signals that were trialled are shown in Figure 1. Following an assessment of signals at TRL from six different suppliers, the signals selected were those that were considered to be the most suitable for use in the trials.

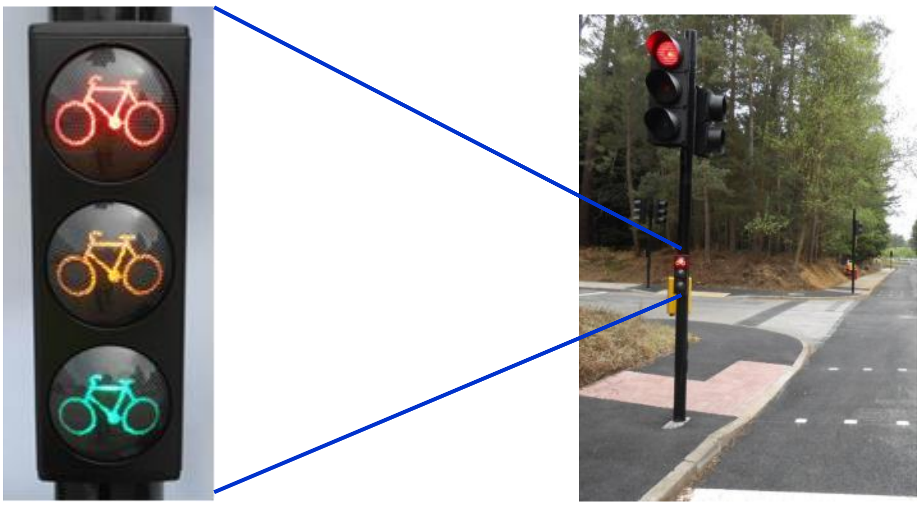

Figure 1 – Low Level Cycle Signals

The scope of this report ("M14") is to present the findings from the first of four sub-trials, assessing the impact of the LLCS by comparing scenarios where the LLCS were covered and uncovered. Additionally, the LLCS were an enabler for layout changes and operational mechanisms in other trials. Specifically, as shown in Table 2, this trial provided a baseline for further trials in which the LLCS: had an 'early release' ("M18"); were on a separate pole ("M19"); and were accompanied by deeper cycle reservoirs ("M24").

Table 2 – Scope of this report (bold) and relation to other trials (italics)

Road layout	LLCS early release	**Cycle trial**	*Cycle groups trial*	**Car trial**	**Motorcycle trial**	**HGV trial**	**Pedestrian trial**	**Partially sighted pedestrian trial**
5m ASL, LLCS on same pole	**Covered**	**M14**		**M14**	**M14**	**M14**		
	Uncovered, no early release						**M14**	**M14**
	Early release (2,3,4,5 seconds)	*M18*		*M18*	*M18*[1]			
5m "cycle reservoir", LLCS on separate pole	*Uncovered, no early release*	*M19*	*M24*	*M19*	*M19*	*M19*	*M19*	
	Early release (2,3,4,5 seconds)	*M19*		*M19*				
7.5m "cycle reservoir", LLCS on separate pole	*Uncovered, no early release*		*M24*	*M24*				
	Early release (2,3,4,5 seconds)			*M24*				
10m "cycle reservoir", LLCS on separate pole	*Uncovered, no early release*		*M24*	*M24*				
	Early release (2,3,4,5 seconds)			*M24*				

1.2 Background

1.2.1 *Existing UK regulations for cycle signals*

The Traffic Signs Regulations and General Directions (TSRGD 2002) shows that it is permissible to signal cyclist movements with a three aspect traffic signal head comprising a full red signal, an illuminated amber cycle logo and an illuminated green cycle logo.

A track trial study was undertaken by TRL to assess the impacts of high level signals with a red cycle aspect (Ball et al. 2014). The objective of the trial was to assess if cyclists responded differently to the Cycle Red signal compared to the Full Red signal. There was no indication from the trial that the type of signal head, whether "Full Red" or "Cycle Red", had an effect on compliance. Trial participants had a good level of understanding of the Cycle Red signal, with no significant differences from their understanding of the Full Red signal. The trial findings provided sufficient confidence that the subsequent trials of Low Level Cycle Signals could progress safely. In addition they provided the evidence for DfT to grant approval for on-street trials of the high level Cycle

[1] Only one level of early start was tested in the M18 motorcycle trial

Red signal. The high level Cycle Red signals were installed at Bow Roundabout on Cycle Superhighway 2 in October 2013.

In August 2013 the DfT also gave approval for on-street trials of high level cycle signals with an early release in Cambridge. A further trial authorisation was granted to Manchester City Council in December 2013 (www.gov.uk 2013). In Cambridge, the cycle signals give an early release at one of the approaches to one junction and were installed as part of a scheme to improve the junction and replace obsolete signals. In Manchester, the signals consist of a standard 3-aspect vehicle signal head with a 4th green cycle symbol aspect mounted underneath the full green aspect. The green cycle aspect operates in a similar way to a filter arrow, providing a few seconds dedicated green time for cyclists before the main traffic flow is released.

1.2.2 Existing UK regulations for ASLs

Advanced Stop Lines (ASL) are a priority measure for cyclists at signal junctions. The marking is prescribed in diagrams 1001.2 and 1001.2A of the Traffic Signs Regulations and General Directions 2002 (as amended). The meaning is that "*vehicles other than cycles must stop at the first line when signalled to do so… forming a reservoir space for cyclists*" (DfT 2003). TSRGD prescribes that the two stop lines must be between 4 and 5 metres apart. This allows the full width of the approach to be available for cyclists waiting at the red light. TSRGD also requires either a gate or a lead-in lane to enable the cyclist to pass the first stop line and legally access the ASL reservoir.

In 2013 the DfT granted authorisation to TfL to install ASL reservoirs up to 7.5 metres deep to cater for the growth in cycle traffic (assets.dft.gov.uk 2013).

1.2.3 Existing research into compliance of cyclists with signals

Research studies have shown that "non-compliance with traffic signals by cyclists is more likely when the cyclist is turning left"; "non-compliance is also more likely when the cross traffic volume is low" (Johnson et al. 2010).

A study by TfL (TfL 2007) found that "The majority of cyclists (84%) obey red traffic lights" and "men are slightly more likely to violate red lights (17% compared to 13%)". Furthermore, red light violations are: "more likely… whilst travelling straight ahead at a junction"; "least likely… when turning right"; and "most common by cyclists travelling towards central London in the morning, and away from central London in the evening".

1.2.4 Existing research into compliance of vehicles with ASLs

In 2005, TRL undertook a research study with over 5,000 observed cyclists on 12 sites in the Greater London area with advanced stop lines. It was found that 36% of all observations involved some form of encroachment by vehicles into the ASL reservoirs. Of those that did encroach into the ASL, about half stopped at least half way into the ASL (Allen et al. 2005).

A similar study of ten sites in London found comparable results; on average motorcycles encroached into at least half the reservoir 60% of the time, compared with 14% of the time for car traffic (Atkins 2005).

1.2.5 Enforcement of signals and ASLs

In August 2013, TfL announced an increased level of enforcement of ASLs by the Metropolitan Police and City of London Police, supported by an engagement and education initiative (www.tfl.gov.uk 2013). Drivers caught crossing the first or second advanced stop lines when the signal is red would be liable for a £60 fixed penalty charge and three points on their licence. The only exception to this rule is if the traffic signal changes from green to amber and drivers cannot safely stop before the first stop line. In addition to stepping up enforcement on motorists, it was announced that cyclists would also be targeted for jumping red lights and issued with a £30 fine if caught doing so.

1.2.6 LLCS in other countries

Many countries throughout the world use smaller sized, low mounted traffic signals with illuminated bicycle logos for signalisation of cycle movements alongside traditional red-amber-green traffic signals.

In Germany small signals with lenses of diameter less than 110mm are mounted at eye-level height for cyclists (RiLSA 1992). In Muenster, guidance states that where low level cycle signals are installed, they should typically be accompanied by an early release. There is no standard amount of time for the early release, although the guidance shows: two examples where the early release is three seconds (both for two-stage left turns); one example where the early release is two seconds (with an ASL); and one example where the early release is four seconds (on a cycle path) (Alrutz 2013). Due to their lower clearance speed, cyclists can also be given an earlier stop signal than the motorised traffic to ensure that the junction is clear of cyclists at the end of the green phase. This time also depends on the size of the junction, and expected clearance speed of the cyclists. ASLs are not always combined with low level signals with an early release (RiLSA 1992). Junctions with cycle signals can have two green phases for cyclists within a signal cycle and can also have extended green phases for cyclists depending on the flow of cyclists (Alrutz 2013).

In Denmark, cycle signals mounted at a lower level than the main signals are widely used to provide separate phases for cyclists at signalised junctions. These signals don't have cycle logos fitted, instead have an additional box sign mounted above them with a white-on-blue cycle logo. In many applications cyclists are often approaching from segregated cycle tracks, rather than from a common traffic lane with ASL, although in some instances the segregation stops before the junction and the inside lane is a 'mixed traffic' lane.

In the Netherlands, cycle signals are often used on cycle paths, "Article 68: Where an illuminated picture of a bicycle is shown, this signal applies to bicycles and mopeds on a cycle/moped track" (www.government.nl 2013).

In France and Spain, low level signals as simple repeaters of the main signal for general traffic are widespread, sometimes with a cycle logo and sometimes without. There is no standard height or angle mounting.

2 Methodology

2.1 Trial site

The trials were conducted at a specially constructed typical "urban" four-arm junction built at TRL's 'Small Road System' (SRS) test facility, see Figure 2. The trial site comprised standard traffic signals and LLCS on each arm. The LLCS were installed at a height of 1.4 metres from the kerb to the centre of the amber aspect and at an angle of 15 degrees away from the kerb. The traffic signals were set on a fixed time loop, driven by a standard traffic signal controller.

Figure 2 – Trial site

2.2 Design variables

Three categories of variables were considered when defining the trial scenarios:

- Design variables (physical design elements)
- Situational variables (specific turning movements by user groups)
- Participant variables (traffic and cycle flows and speeds)

Where possible, variables were chosen to include a baseline value so that observed relative changes could be attributed to the interventions being trialled. However, this could not always be achieved for every variable. Furthermore, it was not possible to test each variable in a single trial; therefore results from a number of different trials were combined.

2.2.1 The Low Level Cycle Signals: covered and uncovered

It would be expected that the behaviour of participants on a test track would vary from that observed on-street, in particular because they know they are under observation. The trial therefore consisted of a "control" and "treatment" experiment, with the LLCS covered and uncovered respectively (see Figure 3) to understand the relative effect of the signals on behaviour, i.e. assuming that effects caused by the artificiality of the experimental design would be common to both.

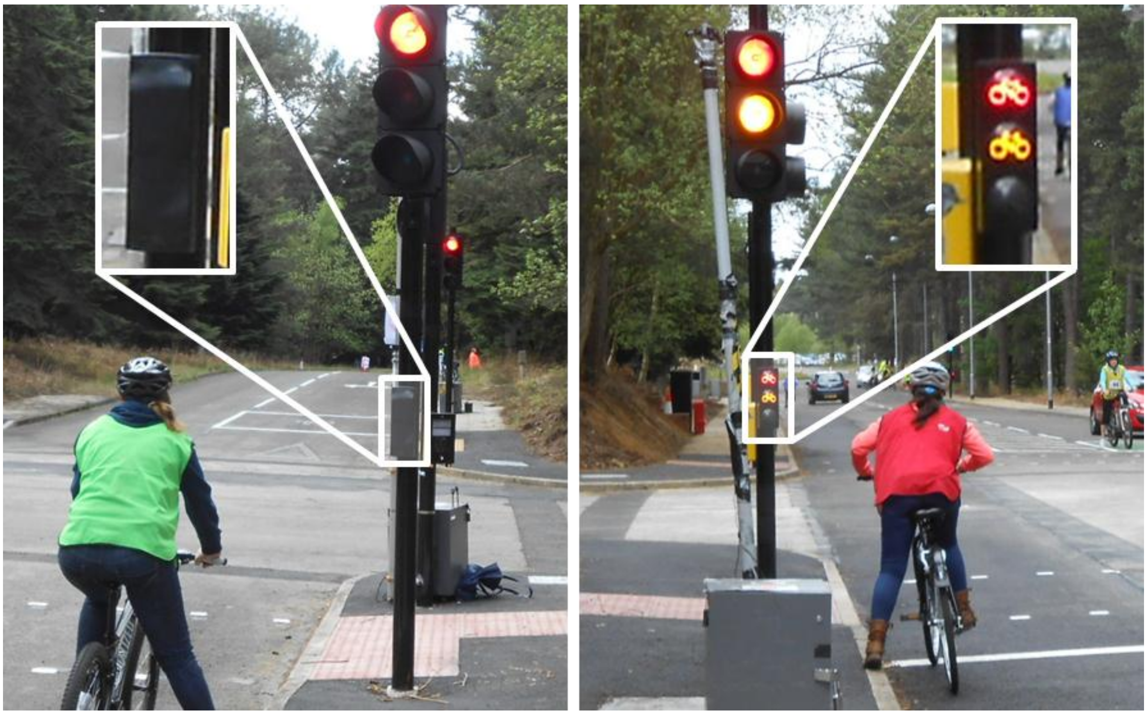

Figure 3 – "Control", LLCS covered (left) and "Treatment", LLCS uncovered (right)

When comparing the uncovered scenario against the covered scenario, statistical tests[2] were undertaken to distinguish whether results were likely to be due to introduction of the LLCS, or whether they were likely to have occurred by chance.

2.2.2 Size of the ASL and location of the LLCS

The road layout of a junction arm is illustrated in Figure 4. In this trial, the LLCS were mounted on the same pole as the main signal, with a 5-metre ASL on each approach at the junction. The LLCS were configured to operate as repeater signals.

[2] The Two Proportion Z-Test was used to assess the differences in proportions, whereas the T Test was used to assess differences in averages.

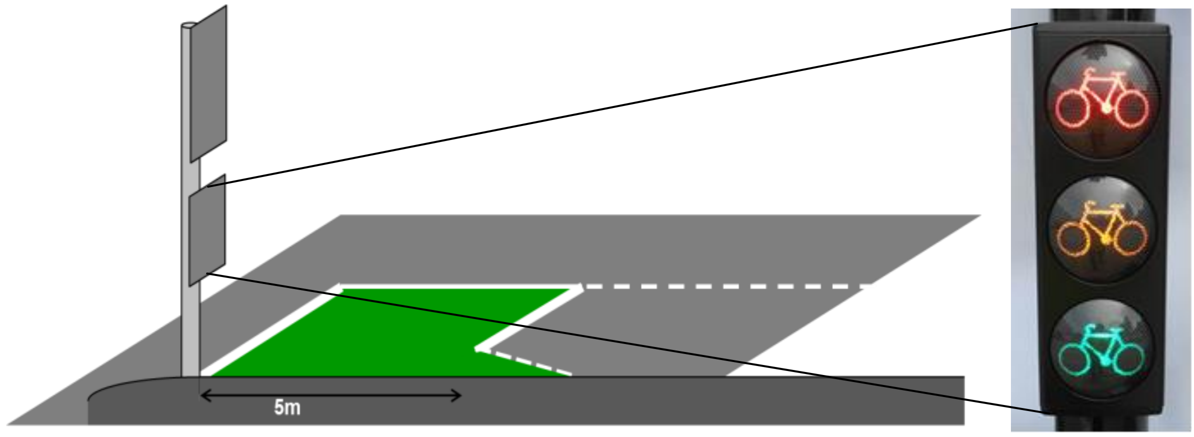

Figure 4 – Locations of signals and size of ASL

2.2.3 Junction layout

A scale drawing of the junction is shown in Figure 5 and a description of the junction layout and placement of the LLCS and other signals is shown in Figure 6 and Table 3.

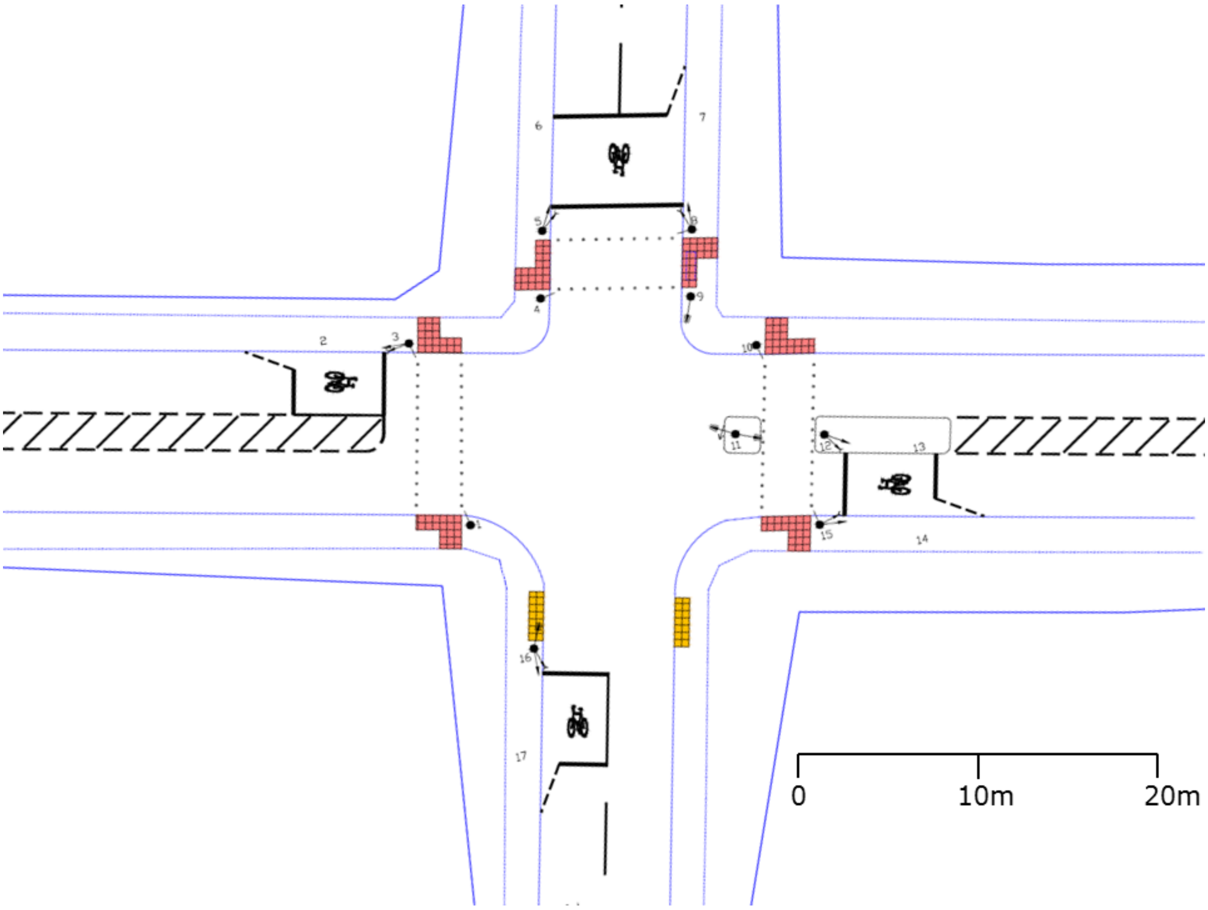

Figure 5 – Junction layout, scale drawing

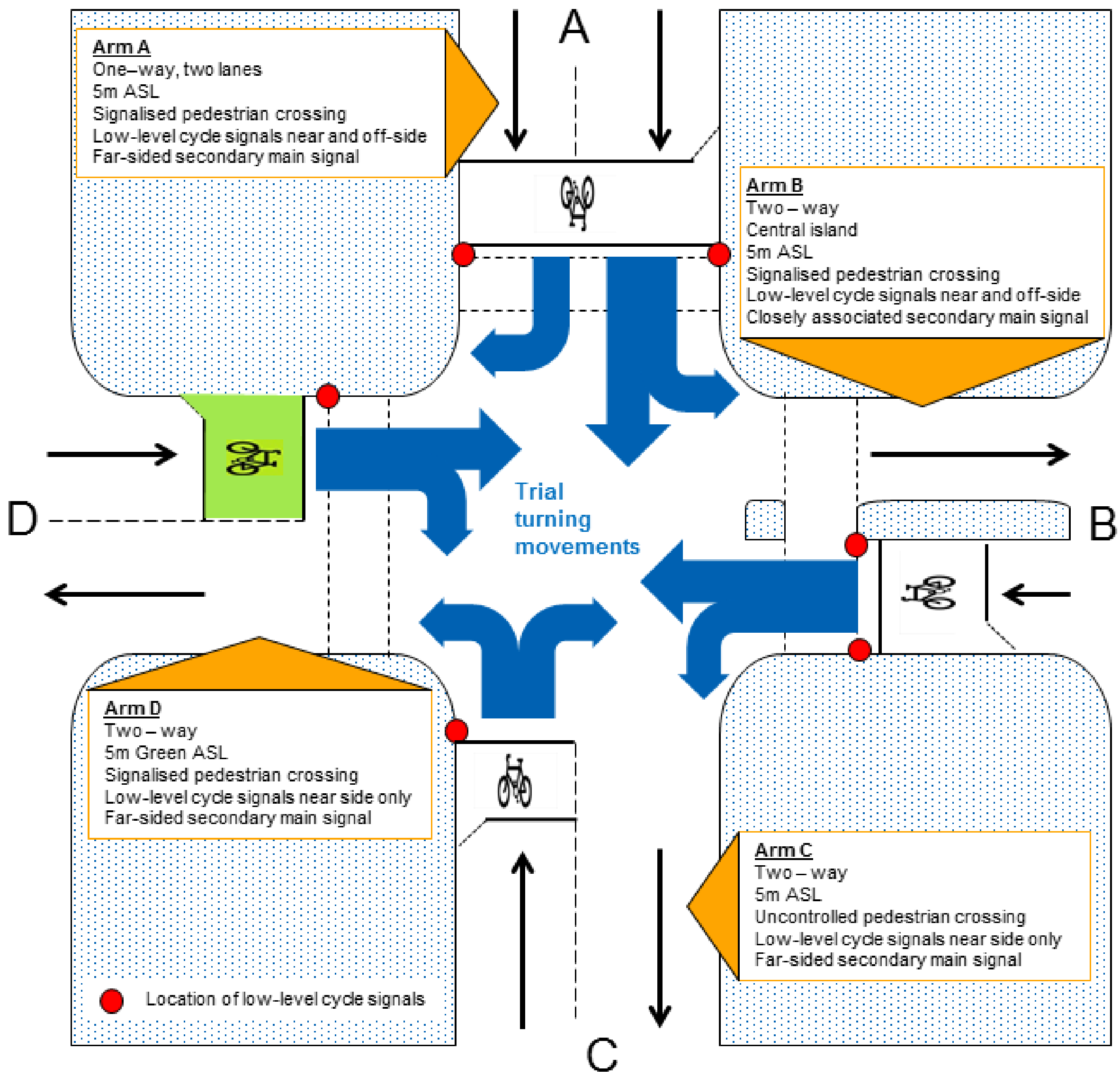

Figure 6 – Junction layout description

Table 3 – Summary of LLCS locations, junction layout and turning movements

Arm	Near-side LLCS	Off-side LLCS	Secondary traffic signal on far side of junction	Closely associated secondary traffic signal	Pedestrian signalised crossing	Right Turn Arrow	Colour of ASL	Turning movements
A	✓	✓	✓		✓		Not painted	Left, Right
B	✓	✓		✓	✓		Not painted	Left, Straight
C	✓		✓				Not painted	Left, Right
D	✓		✓		✓	✓	Green	Straight, Right
P	✓				✓		No ASL	N/A

One of the approaches was a two-lane one-way street, whereas the other three approaches were one-lane two-way streets. LLCS were mounted on the left-hand side of the road on each approach, and in addition, for two of the arms (Arms A and B), there was also an 'off-side' LLCS on the right-hand side of the road. Each approach had an ASL, one of which was green (Arm D), the others remaining unpainted. Each junction arm had a dropped kerb with pedestrian crossing studs; three had pedestrian signals and one was uncontrolled (Arm C). Three of the approaches had a secondary traffic signal on the far side of the junction, whereas one approach had a closely associated secondary traffic signal on an island beyond the pedestrian crossing, but before the junction itself (Arm B). The signals ran on fixed times, in the sequence: Arm A; Arm C; Arm B & Arm D at the same time; Arm D with Indicative Green Arrow; pedestrian phase[3]. There was a slight incline from Arm D up to Arm B.

2.2.4 *Stand-alone crossing layout*

LLCS were also mounted on a Puffin crossing (P) away from the junction. This crossing had near-sided pedestrian units fitted, unlike the junction which was fitted with far-sided pedestrian signals.

2.3 Other variables

2.3.1 *Participant types and trial days*

Trials were conducted for six different road user groups over ten days, with a total of 248 participants: 103 cyclists (3½ days); 58 car drivers (2 days); 31 motorcyclists (1 day); 15 HGV drivers (1 day); 31 pedestrians (1 day) and 10 partially sighted pedestrians (1 day). The number of days of trialling was determined by the target sample sizes of 40 independent observations for cyclists and 30 independent observations for other road users; see Appendix B for the sample size collected.

For safety reasons it was not possible to trial with participant cyclists and participant car drivers at the same time. Results have therefore been compared using data from the participant cyclists from the cycle trial and the participant car drivers from the car trial.

2.3.2 *Controlled vehicles/cycles*

In some cases there were other vehicles/cycles present at the junction, which were controlled by TRL staff. Table 4 lists the scenarios that were tested: the types of participants are listed in each column and where there were other controlled vehicles these are shown by a tick in each row.

Table 4 – Controlled vehicles used in each of the trials

<table>
<tr><th rowspan="2"></th><th colspan="6">Type of participant</th></tr>
<tr><th>Cycle trial</th><th>Car trial</th><th>Motorcycle trial</th><th>HGV trial</th><th>Pedestrian trial</th><th>Partially sighted pedestrian trial</th></tr>
<tr><td>No other vehicles</td><td>✓</td><td>✓</td><td>✗</td><td>✓</td><td>✗</td><td>✗</td></tr>
<tr><td>With controlled cyclist</td><td>✗</td><td>✓</td><td>✗</td><td>✗</td><td>✓</td><td rowspan="2">✓</td></tr>
<tr><td>With controlled car</td><td>✓</td><td>✗</td><td>✓</td><td>✗</td><td>✗</td></tr>
</table>

[3] Pedestrian trial only

In the cycle trial, participants encountered the junction both with and without a controlled car; similarly in the car trial, participants encountered the junction both with and without a controlled cyclist. Motorcyclists experienced the junction always with a car, whereas for safety reasons the HGV trial involved no other road users. The pedestrian trial had some controlled cyclists, whereas the partially sighted pedestrian trial also included both controlled cyclists and controlled cars.

2.3.3 Turning movements

Due to Arm A being a one-way street, there were nine possible turning movements. It was decided however to exclude the straight-on movement from Arm A in order to make the experiment more balanced, see Table 3. Cars did not make the left turn from Arm A, because of restrictions imposed by the optimal 'reset routes'[4]. The HGV trial involved only straight-on movements because of the tight turning circles on the junction. Arm B and Arm D changed to green at the same time and so right-turning vehicles from Arm D had to turn across the path of traffic from Arm B.

2.3.4 Release times

Cyclists, car drivers, motorcyclists and HGV drivers were released at timed intervals so that they were always faced with a red signal when arriving at the junction. In both the cycle trial and car trial, the cyclist always approached the junction ahead of the car, with the cyclist being released first and the car being released ten seconds later. In the motorcycle trial, the car was released five seconds after the motorcyclist. The cycle trial included a scenario where two participants were released at the same time from the start point; this made it possible to assess whether the behaviour of the cyclists was influenced by the presence of other cyclists. In the other trials only one participant was released at a time from the start point.

2.4 Trial setup

2.4.1 Daily structure

The typical daily structure involved four groups of participants, two in the morning and two in the afternoon. Groups would undertake the trial in two or three 'sessions' of approximately 30 to 40 minutes. The schedule was designed so that participants would experience the signals both covered and uncovered (see Section 2.2.1) and possibly with and without controlled vehicles (see Section 2.3.2).

From experience with previous trials it was expected that there would be a learning effect with the participants, i.e. where their behaviour may have modified as they became more familiar with the trial. In order to overcome this issue, the order of the sessions was chosen so that the participants encountered the combinations of variables in different orders.

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[4] See Section 112.4.2 for examples of 'reset routes'

2.4.2 Runs within a session

The different groups of road users experienced the LLCS a number of times over a period of between approximately 80 and 130 minutes. They traversed eight numbered routes, which continually looped them through the junction and back to a different start point. Routes 1-4 from the cycle trial are shown in Figure 7. Routes 5-8 are shown in the Appendix B, along with the routes for the other trials.

In the HGV trial, each driver was accompanied in their cab by a facilitator, who instructed them when to approach the junction. In the pedestrian trial, participants walked a predetermined route to cross each of the four junction arms as well as the Puffin crossing. A similar trial was conducted for partially sighted pedestrians, where each participant was accompanied by a researcher from TRL who guided them and recorded their behaviour and responses to an in-trial interview.

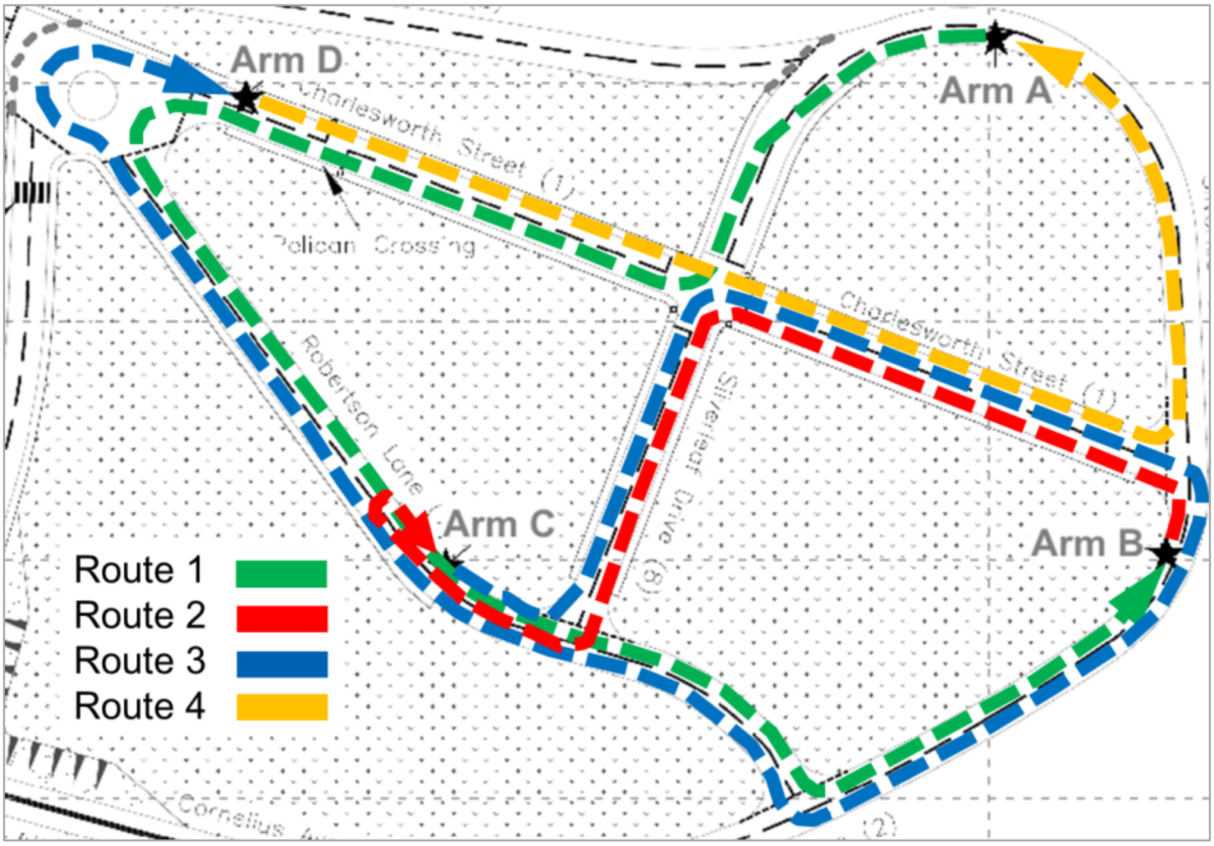

Figure 7 – Cycle trial: routes through the junction and to next starting point (Routes "1-4")

2.5 Study objectives and research questions

The overall objective of LLCS is:

i. to provide a dedicated signal for cyclists at traffic junctions that enables additional prioritisation to be given to cyclists and reduces potential conflict points between cyclists and other road users at junctions.

Further objectives include:

ii. to increase the compliance of cyclists with red signals;

iii. to improve compliance of drivers with the ASL;

iv. to provide a more comfortable viewing position for cyclists;

v. to encourage modal shift to cycling; and

vi. not to adversely affect safety or journey times of all road users.

The main study objective was to gather evaluation evidence on LLCS used as repeaters of the main traffic signals in the context of an application to the DfT for an experimental order for an on-street trial. Several specific research questions were set, which instructed the design of the trial and the analysis. These research questions were grouped into the six more general questions as listed below.

1. Did people understand the LLCS?
2. What attitudes did people have towards the LLCS?
3. Did people use the LLCS information?
4. Did the LLCS affect compliance: i) whether cyclists stopped at a red light; ii) where people waited?
5. Did the LLCS affect how people moved off as the signals changed to green?
6. Did the LLCS affect perceived safety?

2.6 Measures collected to answer the research questions

Measures were collected to inform each of the research questions through a combination of a post-trial questionnaire and video analysis.

2.6.1 Post-trial questionnaire

A paper questionnaire was given to each participant for self-completion after they had completed the track trial. The majority of the questions were common across each of the road user groups, although there were some questions tailored to the various road users.

Each questionnaire included classification questions on participants' demographic and also their level of experience with traffic signal junctions and ASLs. Participants were asked about their experiences from the trial in relation to: the signals; their stopping behaviour; and also their experiences when going through the signals for each of the junction approaches. Finally, their attitudes towards LLCS were investigated.

All participants who took part in the trial completed the questionnaire; see Section 2.3.1 for the number of participants in each road user group. The responses to closed questions are presented in graphs with vertical bars, whereas responses to open questions have been classified and are presented in graphs with horizontal bars.

2.6.2 Video analysis

The video analysis of the behaviour at the junction was aimed at extracting data to describe the behaviour of road users with regards to 'moving behaviour' and 'stopping behaviour'. See Appendix B for a description of the locations of the cameras.

2.6.2.1 *Measures relating to the moving behaviour of the road users*

The moving behaviour of the participants was described through timing points as they passed fixed locations, as well as relative to the signal changes, as shown in Figure 8.

The signal timing points were as follows (on each arm):

- Timing points at fixed locations
  - TP1 – 15 metres before main stop line
  - TP2 – 'ASL Entrance' (5 metres before main stop line)
  - TP3 – 'ASL Exit' (i.e. the main stop line)
  - TP4 – 'Junction Entrance' (i.e. the first set of pedestrian crossing markings; 1.7 metres after the main stop line)
  - TP5 – 'Junction Exit' (i.e. the second set of pedestrian crossing markings on the exit arm)
- Other timing points
  - Time traffic signals changed from Red to Red & Amber
  - Time the cycle/vehicle stopped moving
  - Time the cycle/vehicle started moving

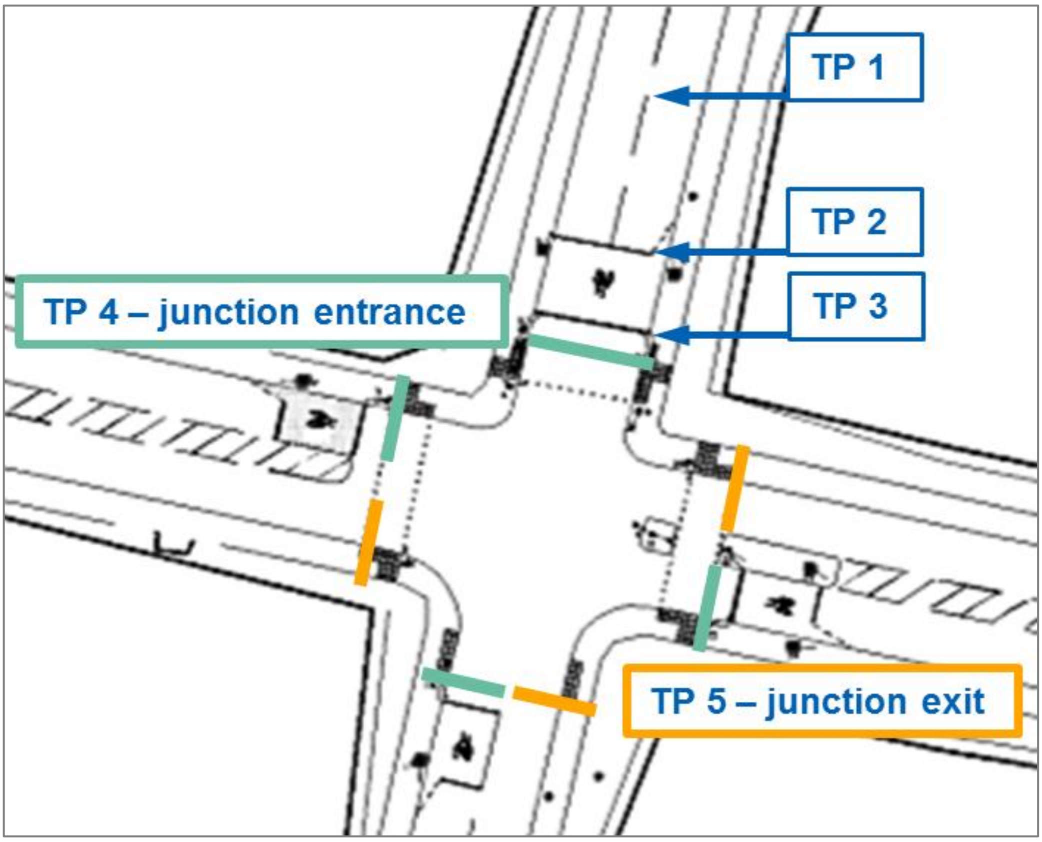

Figure 8 – Timing points at fixed locations

Three measures of the moving behaviour of road users were defined.

1. **'Reaction Time'** – described how quickly the participants react to the LLCS changing to Red & Amber (time the wheels started moving minus time the LLCS goes to Red & Amber).
2. **'Entry Time'** – described how long it took to enter the junction relative to the signals changing to Red & Amber; different to the Reaction Time, in that changes in stopping position are implicit within the Entry Time (time the wheels passed Junction Entrance (TP4) minus time the LLCS goes to Red & Amber).
    a. For the cycle trial, this described the time advantage that cyclists have in entering the junction.
    b. For the car trial, motorcycle trial and HGV trial, this described the time delay that other road users had in entering the junction[5].
3. **'Clearance Time'** – described how long it takes the participant to clear the junction (Time the wheels passed Junction Exit (TP5) minus time the LLCS signal goes to Red & Amber).

For each of these three measures, comparisons were of interest within a trial for a particular road user and also comparisons between the values for participants in the cycle trial and the values for the participants in the car, motorcycle and HGV trials.

[5] In the M14 trial, the LLCS and the main signals go to green at the same time; however, in some later trials the LLCS change to green earlier

2.6.2.2 Measures relating to the stopping behaviour of the road user

For the cycle trial the stopping behaviour of the cyclists was defined using the stopping zones in Figure 9, where the position of the cyclists' front wheel was noted longitudinally and laterally with respect to the ASL. For this exercise those cyclists who did not stop were excluded.

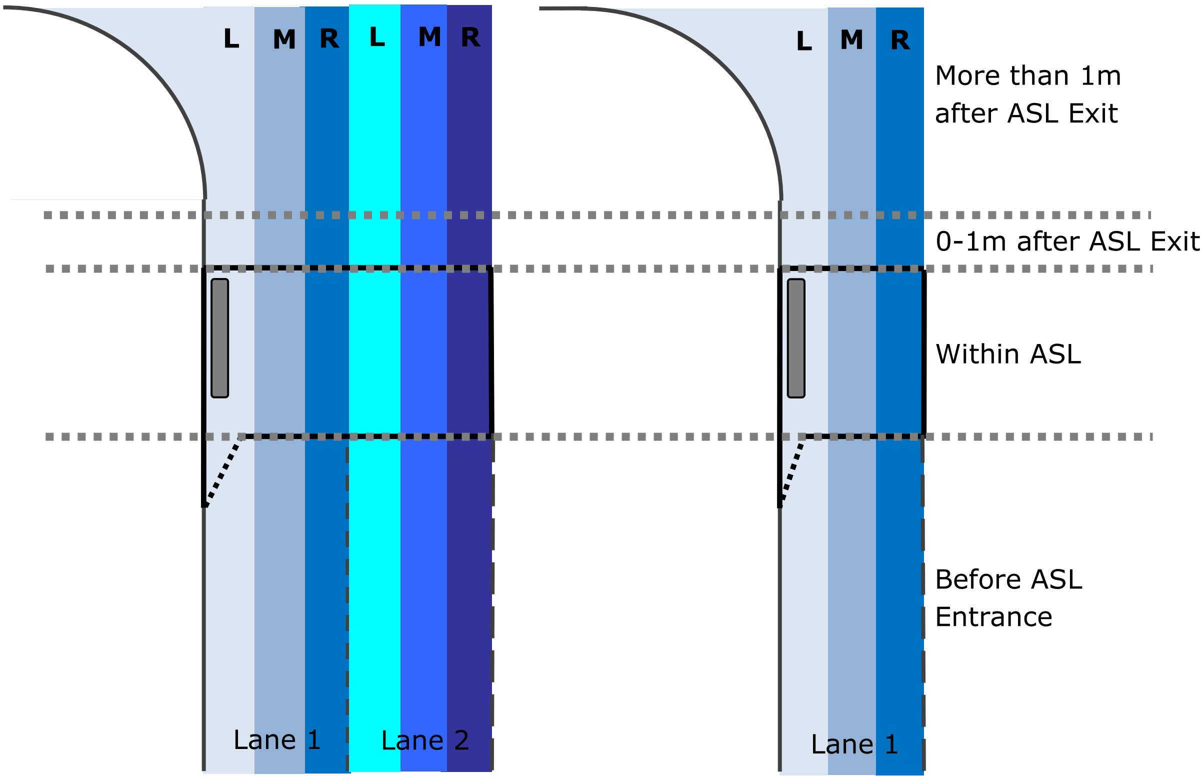

Figure 9 – Cycle trial: stopping zones

For the car trial, motorcycle trial and HGV trial, the 'Within ASL' stopping zone was split into four smaller zones. In the car trial and HGV trial, data was not recorded on the lateral stopping position, although it was recorded for the motorcycle trial. In the pedestrian trial, data was captured on when participants arrived at the crossing, when they crossed and where they crossed.

2.7 Limitations

The situations presented to the participants were necessarily lacking some aspects of realism; some limitations of the experiment are listed below.

Compliance is difficult to study accurately on a test track, with participants often being more compliant than in the real world. Specifically in this experiment, the following factors may have had an effect of the compliance of participants:

- Participants were aware they were being studied.
- They were not under time pressures.

Other limitations of the study, which affected realism included:

- There were relatively low levels of traffic.
- For safety reasons, the trial was arranged so that the cyclists arrived at the junction before the drivers, i.e. cyclists never approached the junction from

behind waiting vehicles. In particular this excluded the potential for conflicts with vehicles turning left across the path of cyclists behind them going straight on.

- This trial did not consider features such as bus stops, on-street parking, loading/drop-off zones or pedestrian crossings, all of which would influence cyclist behaviour.
- Participants had clear information about their route.

Previous experiments have been conducted under similar 'artificial' conditions, where behaviour is often found to differ from reality. However, the extent of immersion in the conditions simulated has been found to be sufficient for participants to realistically adapt their natural behaviour. Thus, it is possible to investigate the relative (although not absolute) effects of controlled design changes.

The extent of the change may be over, or under, represented; however, the direction of the change would be expected to occur in reality and the effects can therefore be assessed as to whether they would be beneficial. Specifically, this trial enabled relative comparisons to be made between the LLCS being uncovered and covered.

3 Findings

3.1 Did people understand the LLCS?

Table 5 – Research questions on understanding

Road user	Theme	Research question	Video	Q'naire
All road users	Understanding	Did they understand the purpose of the LLCS?	✗	✓
		Who did they understand the LLCS to be for?	✗	✓
		To what extent did they confuse LLCS with Toucan crossings?	✗	✓
Pedestrians and partially sighted pedestrians	Understanding	To what extent did pedestrians understand that the LLCS were for cyclists on the road?	✗	✓
		To what extent did they confuse LLCS with Toucan crossings?	✗	✓

3.1.1 Understanding of the LLCS

Following the track trial, participants were shown a picture of the cycle signals and asked, "What do these signals mean to you?". Their responses are summarised in Figure 10.

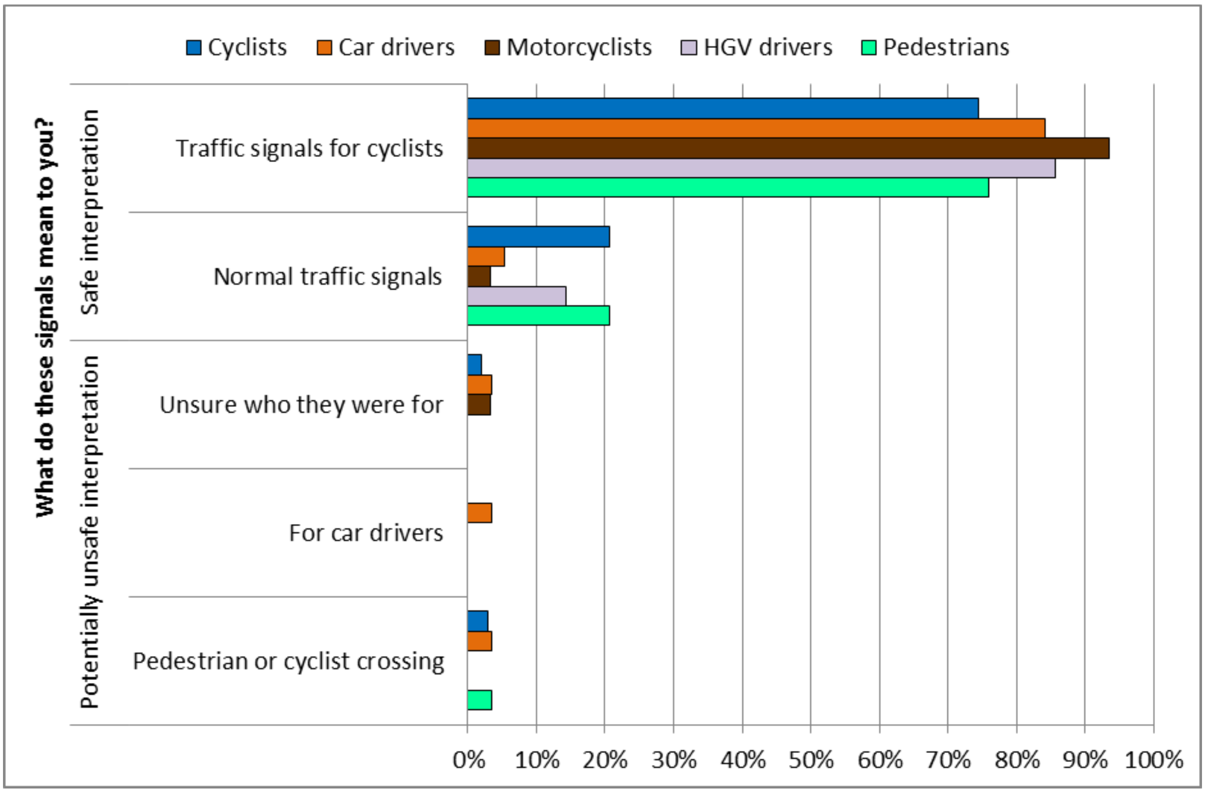

Figure 10 – Understanding of the LLCS (questionnaire)

Most of the participants in the trials understood the repeater LLCS: approximately 75% of cyclists and pedestrians; 85% of car drivers and HGV drivers; and 95% of motorcyclists. Also, many of the remaining respondents interpreted them as normal traffic signals, but did not explicitly state they were for cyclists, and so this is not a safety concern.

For example one of the cyclists explained:

> *"[They are] at a lower level for cyclist to see." (Cyclist)*

One of those who did not mention cyclists said:

> *"The same as the main traffic signals." (Cyclist)*

Examples of explanations given by other road users were:

> *"I would assume that they are specifically for cyclists not motorists. I would wait for the main lights to change before driving a vehicle through them." (Motorcyclist)*
>
> *"They apply only to pedal cycles. As a motorist I continue to obey the main traffic lights." (Car driver)*
>
> *"They give cyclists an eye level view of the traffic light." (Pedestrian)*

There were, however, approximately 10% of car drivers and 5% of cyclists who were unsure, or misinterpreted, their meaning. One of those who were unsure of the meaning said:

> *"Confused at first as I was not sure they were going to change the same as the vehicle big lights." (Cyclist)*

Two participants, both car drivers, said the cycle signals were for car drivers:

> *"Like traffic lights but for cyclists and drivers." (Car driver)*

Six participants (out of 233) confused the cycle signals with cyclist or pedestrian crossings.

> *"Cyclists on the pavement may cross the road cycling when green." (Cyclist)*

Perhaps of more concern, was the one pedestrian who thought they were to indicate when pedestrians and cyclists should cross the road:

> *"Cycles can cross." (Pedestrian)*

This suggests that they had confused them with a Toucan crossing and mistakenly thought they had priority.

3.1.2 Partially sighted pedestrian trial

All ten partially sighted participants who experienced the signals understood either that the LLCS were not for them or that they were explicitly for cyclists. None of the participants suggested that that they would consider crossing when the LLCS showed a green phase at any point on the trial. This did not vary for any of the types of crossing.

F1.a. Most (75% to 95%) understood the repeater LLCS.

F1.b. A small percentage (less than 5%) of pedestrians, cyclists and car drivers misinterpreted the LLCS as indicating when pedestrians should cross the road, so they could have incorrectly judged that they had priority.

F1.c. All partially sighted participants who experienced the signals understood that either the LLCS were not for them or that they were explicitly for cyclists.

Further information in Appendices D & E.

3.2 What attitudes did people have towards the LLCS?

Table 6 – Research questions on attitudes

Road user	Theme	Research question	Video	Q'naire
All road users	Attitudes	Who would benefit and what were the perceived benefits?	✗	✓
		Did people like the LLCS?	✗	✓
		What improvements did people suggest for LLCS?	✗	✓
		Would LLCS make people more likely to cycle on busy roads?	✗	✓
	Trial experiences	Did people experience difficulties?	✗	✓

3.2.1 Who would benefit and what were the perceived benefits?

After being asked about their experiences in the trial, participants were then asked, "Thinking about the 'Low Level Cycle Signals' which you have experienced today, who do you think would benefit from them? (Tick all that apply): cyclists on the road; cyclists elsewhere; cyclists with an electric bicycle; scooter riders; motorcyclists; other (please specify)".

Most participants (around 90% of cyclists, car drivers and pedestrians and almost 80% of motorcyclists and HGV drivers) thought that cyclists on the road would benefit from LLCS used as repeaters for the main signals. Cyclists elsewhere, cyclists with electric bikes, scooter riders and motorcyclists were thought to benefit by between about a quarter and half of participants.

Participants were then asked to explain their answer; comments were classified as shown in Figure 11[6].

[6] Sample size: 103 cyclists; 58 car drivers; 31 motorcyclists; 15 HGV drivers; and 31 pedestrians; 238 in total.

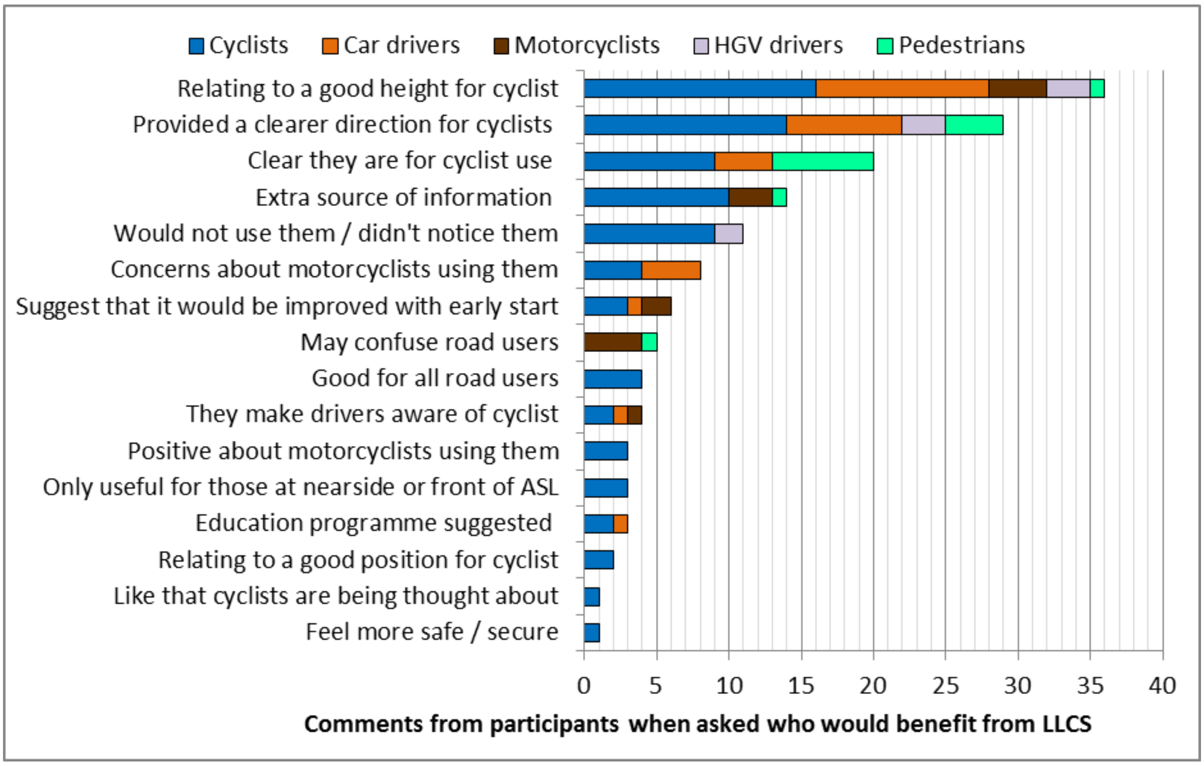

Figure 11 – Explanations when asked about who would benefit (questionnaire)

In their explanations of their answers, cyclists mainly saw LLCS in a positive light, as a useful additional piece of information dedicated to cyclists, which is provided at an appropriate height for them:

> *"This signal gives clear indication to cyclists when to stop/get ready/go, whilst in their normal line of sight" (Cyclist).*

Some of the car drivers thought that the LLCS would make it clearer for other road users:

> *"It will benefit drivers knowing to be aware of cyclists." (Car driver)*

In general the pedestrians thought the LLCS were beneficial, for example:

> *"I think cars and traffic have "regular traffic lights", pedestrians have "pedestrian lights" so it stands to reason that cyclists should have the same care, protection, guidance and to concentrate on their signals too". (Pedestrian)*

However, there were concerns from a minority of cyclists, with some saying that motorcyclists would use the signals when they were not intended to.

> *"Scooter and motorbike riders might attempt to use the lights when they were not supposed to." (Cyclist)*

Some mentioned that only cyclists at the front or the near-side of the ASL would be able to see them, for example:

> *"Positioning (height/angle) - only potentially of benefit to cyclists beside kerb and at front of any queue." (Cyclist)*

Some motorcyclists commented on the number of signals and the confusion this might cause. One pedestrian shared this view.

"Too many signals on same piece of road - more confusion will arise." (Motorcyclist)

Some participants said that they did not notice the LLCS or would not use them.

Overall, LLCS were seen as beneficial by most of the participants across all road user categories. However, a few hypothetical concerns were raised by cyclists with regard to being able to see them in crowded conditions and misuse by scooter and motorcycle riders.

3.2.2 Did people like the LLCS?

A qualitative assessment was made to classify the comments about the LLCS in response to several questions (including the general comments at the end of the questionnaire) into three categories: in favour (positive), against (negative) and neutral; this last group also included people who made both positive and negative comments. These have been summarised in Figure 12. It should be re-emphasised that these attitudes were to LLCS being used solely as repeaters of the main signal.

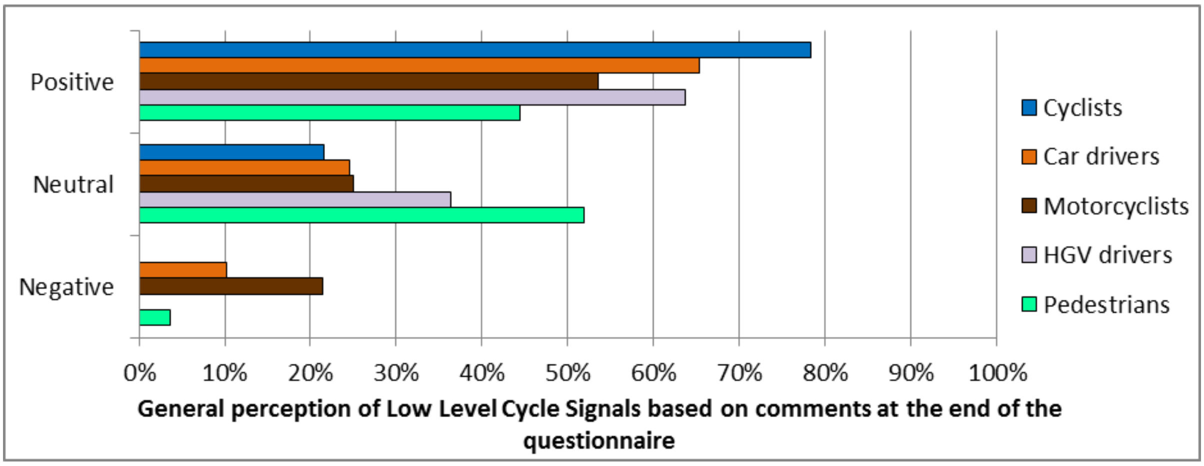

Figure 12 – Classification of attitudes (questionnaire)

The majority (about 80%) of cyclists were in favour of them. With the exception of motorcyclists, over 90% of other road user groups were not negative towards them.

About 50% of pedestrians were ambivalent, but this was generally associated with not noticing the signals or not using them.

"Until this questionnaire I don't think I realised the signals were not of the usual type." (Pedestrian)

Motorcyclists were the least in favour of the signals with over 20% considering them as negative. These comments were associated with issues such as too many signal heads causing confusion (see Section 3.2.1), some safety concerns (see Section 3.6.3) and a lack of perceived benefits.

"The signals are useful but probably not so great to justify the expense." (Motorcyclist)

3.2.3 What improvements did people suggest for LLCS?

Participants were asked, "Do you have any suggestions for improving the signals you used today?". The suggestions were classified as illustrated in Figure 13.

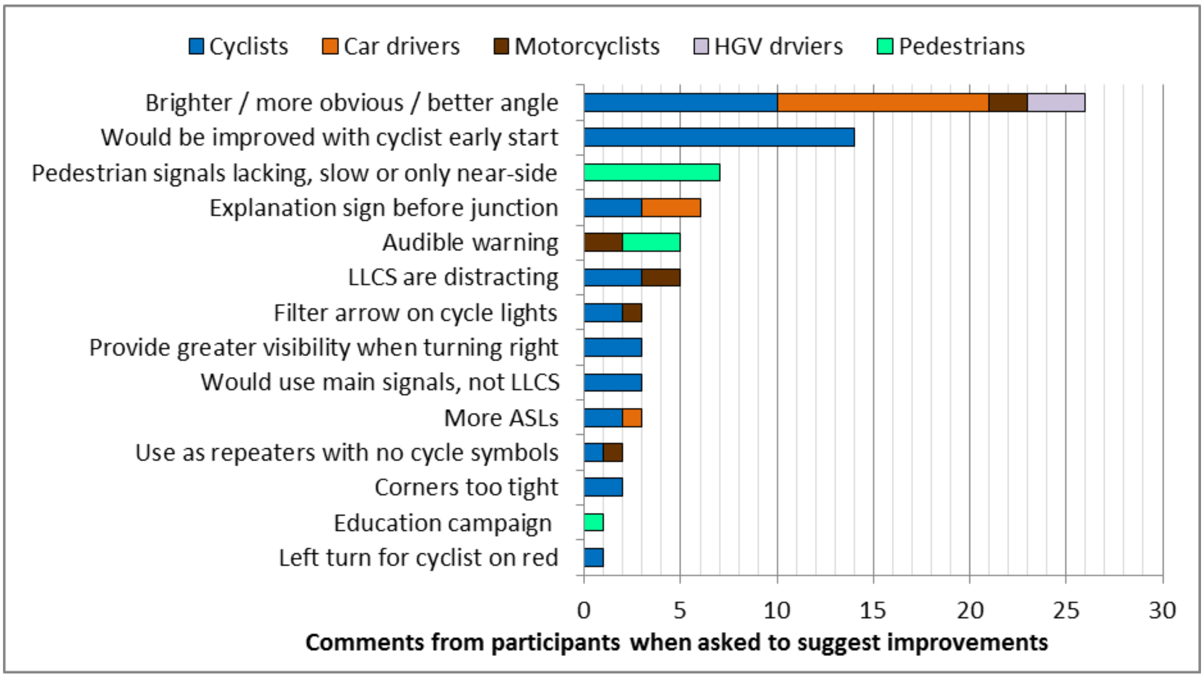

Figure 13 – Comments when asked to suggest improvements (questionnaire)

The most commonly mentioned suggestions by cyclists were to provide an early release for cyclists.

> *"If the low level signals change a couple of seconds before the main ones it could allow the cyclist to get moving before the traffic behind." (Cyclist)*

> *"If low level signals are to be employed, [they] could enable earlier departure for cyclists (obviously this would lower traffic capacity)." (Cyclist)*

A few cyclists said they were unsure about the purpose of the cycle signals if they are in time with the main signals:

> *"Why have bicycle symbol, especially if just repeating main lights?" (Cyclist)*

> *"They were a little superfluous, unless there is a timing advantage." (Cyclist)*

There were a range of suggestions to make the LLCS more obvious, in particular through making them bigger.

> *"Maybe make the cycling signals a bit bigger. I didn't feel I could trust them without checking the bigger traffic lights." (Cyclist)*

There were also suggestions from drivers, motorcyclists and pedestrians about making the cycle signals more visible by using brighter lights, slightly larger signals and adding a high visibility border. Some drivers thought they would also benefit from low level lights.

> *"I think car drivers would benefit from low level lights too. Especially on junctions where a light on the opposite side of the road is not installed/appropriate." (Car driver)*

> *"The signals need to be more pronounced as in certain driving conditions they could be easily missed by the car driver; maybe just two colour signals or larger." (Car driver)*

One car driver suggested using signs to warn drivers about the cycle signals. Two of the motorcyclists suggested audible warnings to indicate that the signals are about to change and one suggested a 'countdown' to the signals changing.

Some comments from cyclists concerned the fact that the cycle signals on the left are not helpful for turning right, for example:

> *"[I] only looked at the low level signals when I was the same side of the road as they were. If I was turning right and there wasn't one there I'd look at the main signals." (Cyclist)*

A few comments were not in favour of the signals, for example because there are enough signals already, they are not considered necessary and because cyclists are perceived by some as ignoring red signals.

Earlier in the questionnaire, participants were asked what they thought about the height and angle of the LLCS. Over three-quarters of the cyclists said that the height was 'about right', 15% thought the signals would be better if they were higher, 2% would have preferred them lower and about 5% said they didn't know. About 70% of cyclists thought the angle was 'about right' and just over 20% thought they would be better if they were angled so that they pointed more towards the road, none said they should point more away from the road and about 10% said they didn't know.

3.2.4 Would LLCS make people more likely to cycle on busy roads?

The influence of these facilities on willingness to cycle in London was inferred by asking, "Do you think it would affect how often you cycle in busy traffic if more junctions were like this? (Please tick one): yes; no; it depends; don't know". About 25% of pedestrians and motorcyclists, 20% of cyclists and 10% of car drivers said 'yes'. Two-thirds of motorcyclists and about 50% of the other participants said 'no'. Between 5% and 15% said 'It depends' and between 5% and 25% said 'Don't know'. These results should be treated with caution, because they do not mean that they definitely would cycle, rather it means that they would be more likely to consider cycling.

3.2.5 Did people experience difficulties?

Participants were also asked about how easy it was to make each of the turns at the junction, while pedestrians were asked about how easy it was to cross at each point. Responses largely consisted of comments about the trial conditions, in particular the tight geometry of the junction, rather than the signals.

F2.a. 90% of cyclists, car drivers and pedestrians and almost 80% of motorcyclists and HGV drivers thought that cyclists on the road would benefit from LLCS. The main reason given was that it was a useful additional piece of information, provided at an appropriate height for cyclists.

F2.b. About 80% of cyclists were in favour of LLCS. With the exception of motorcyclists, over 90% of most other road user groups were not negative towards LLCS, with about 45% to 65% being in favour of the LLCS.

F2.c. The most commonly mentioned suggestions for improvements were to provide an early release (from cyclists) and to make the signals bigger and more obvious (from all road users).

F2.d. Over three-quarters of the cyclists said that the height was 'about right' and about 70% of cyclists thought the angle was 'about right'.

Further information in Appendix D.

3.3 Did people use the LLCS information?

Table 7 – Research questions on use of LLCS

Road user	Theme	Research question	Video	Q'naire
Cyclists	Trial experiences	What did the cyclists look at when deciding when to enter the junction? What was the most important factor in their decision?	✗	✓
Car drivers, motorcyclists and HGV drivers	Trial experiences	What did the other road users look at when deciding when to enter the junction? What was the most important factor in their decision?	✗	✓
Pedestrians and partially sighted pedestrians	Trial experiences	What did the pedestrians look at when deciding cross the road? What was the most important factor in their decision?	✗	✓
		To what extent did pedestrians use the information? - When they knew it was for road-cyclists? - When they misunderstood it?	✗	✓

3.3.1 Cyclists, car drivers, motorcyclists and HGV drivers

Following the track trial, participants were presented with photographs of each arm of the junction and asked which of the signals they looked at as they approached and as they were waiting to turn. They were then asked to note which was the most important to them.

3.3.1.1 Did they look at the LLCS?

As discussed in Figure 6 in Section 2.2.3, there was a near-side LLCS on the left on each of the approaches; on two approaches (Arm A and Arm B) there was also an additional off-side LLCS.

Cyclists typically used the main signals when approaching the junction and then used the LLCS when waiting at the junction.

"…found the lower cycle lights useful when waiting at the lights, but not when approaching the junction" (Cyclist)

Figure 14 shows the proportion of participants who looked at the LLCS on the left, pooled across all four junction approaches.

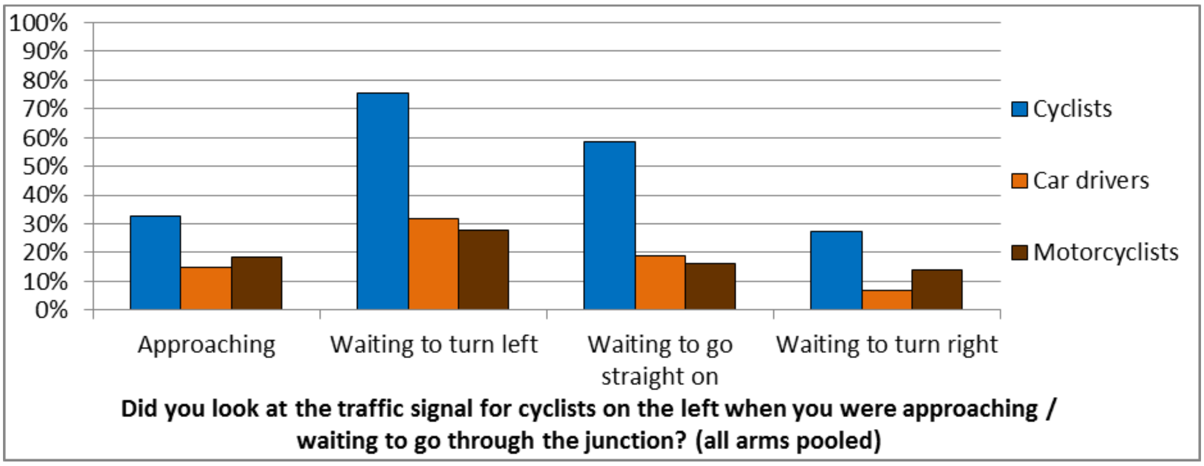

Figure 14 – Proportion of participants who said they looked at the LLCS on the left (questionnaire)

When waiting to turn left (Arms A, B, and C), the signal for cyclists on the left was mentioned by approximately 70% to 80% of cyclists, which was more than the other signals in each instance. Prior to going straight on at Arm D, cyclists also mentioned looking at the cycle signal on the left more than other signals (71%). However, on Arm B fewer cyclists looked at the cycle signals on the left (47%). While waiting to turn right (Arms A, C, and D), about 20 to 30% of cyclists mentioned looking at the cycle signals on the left.

On Arm B, about 10% of cyclists looked at the off-side cycle signal on the centre island when approaching the junction or waiting to turn left; when waiting to go straight on this proportion was slightly higher (26%). About half of cyclist participants said they looked at the off-side cycle signal on Arm A when turning right; although this result is based on a small sample size and so should be treated with caution[7].

Some car drivers and motorcyclists (10% to 20%) mentioned looking at the LLCS on the left when approaching the junction. Slightly more used them when turning left, rather fewer for going straight on and even fewer for turning right. Motorcyclists were more likely than car drivers to say they looked at the cycle signals while waiting to turn right.

In summary, most cyclists used the near-side LLCS when turning left (over 70%) and going straight on (about 50% to 70%). About half of cyclists turning right used the off-side signal heads where these were available. Higher proportions looked at the near-side signal heads for turning left than when going straight on, which in turn was higher than when turning right. The opposite relationship existed for the off-side signal heads where present. It would therefore appear that cyclists do use them, but that off-side signal heads may be useful if there is a high turning proportion of cyclists at the junction.

[7] Sample size = 15 ; this result will be updated in subsequent trials

3.3.1.2 What was the most important piece of information

When turning left the LLCS were the most important for a large proportion of cyclists (45% on Arm A, 51% on Arm B, 57% on Arm C); some cyclists stated that the main signals on the left were the most important factor (35% on Arm A, 29% on Arm B, 20% on Arm C).

When going straight on, not as many cyclists stated that the LLCS were the most important factor as when turning left, but they were still the most important factor for some cyclists (9% on Arm B, 25% on Arm D).

When turning right many participants stated that the main traffic signals, either right, left or the secondary traffic signal in front were the most important factor. On Arm C and Arm D, whether the junction was empty was stated as the most important factor for many cyclists (27% and 26% respectively) and motorcyclists (35% and 40% respectively). Very few cyclists stated that the LLCS were the most important factor when turning right for the approaches with only the near-side LLCS (9% on Arm C, 6% on Arm D). On the approach with the near-side LLCS and off-side LLCS (Arm A), about two-thirds said that either the main signal on the right or the secondary traffic signal were the most important factor; meanwhile about 20% said the near-side LLCS were the most important and 10% said the off-side LLCS were the most important, although this result is based on a small sample size and so should be treated with caution[8].

3.3.2 Pedestrians

In the questionnaire following the pedestrian trial, many participants (30%) said that they used the LLCS (in addition to other sources of information) when deciding to cross at controlled crossings at the junction (Arm A, B, D) and also at the Puffin crossing. However, none stated that these signals were the most important factor in making their crossing decision. At the uncontrolled crossing (Arm C), about half said that they used the LLCS (in addition to other sources of information) when deciding to cross. Furthermore, just over 10% stated the LLCS were the most important factor in their decision to cross at the uncontrolled crossing.

As discussed in Section 3.1.1, there was one pedestrian[9] who said they thought the LLCS were for cycles crossing the road. However, in the later questions this participant said that they didn't look at the cycle signals when crossing the road.

From the comments there was little indication that the LLCS affected pedestrians' decisions to cross the road. Just a few of the pedestrians made reference to the cycle signals when asked for general comments about the junction. Those who did comment about the LLCS suggested that the signals would not affect them, whereas others said they would provide an extra piece of information.

3.3.3 Partially sighted pedestrians

The findings from the partially sighted pedestrian trial suggested that the LLCS would not have an adverse impact on partially sighted pedestrians. This was because partially-sighted pedestrians tended to ignore unrecognised visual clues, and the LLCS were

[8] Sample size = 11

[9] Sample size = 31

judged as sufficiently different from the pedestrian push button units so as not to cause confusion.

F3.a. Most of the cyclists tended to use the LLCS as an extra source of information. In particular approximately 70% to 80% of cyclists used the near-side LLCS when waiting to turn left; about 50% to 70% when waiting to go straight on; and about 20% to 30% when waiting to turn right. About half of cyclists turning right used the off-side signal heads where these were available.

F3.b. At the uncontrolled crossing, about half of the pedestrians said that they used the LLCS, with approximately 10% stating they were the most important factor when deciding to cross. Of those who used the LLCS, none misinterpreted their meaning.

Further information in Appendices D & E.

3.4 Did the LLCS affect compliance: i) whether cyclists stopped at a red light; ii) where people waited?

Table 8 – Research questions on red light compliance and stopping position

Road user	Theme	Research question	Video	Q'naire
Cyclists	Compliance with red light	To what extent did the LLCS affect compliance with red lights?	✓	✗
	Longitudinal stopping position	To what extent did the LLCS affect the compliance of cyclists stopping past the ASL Exit? / Did the LLCS affect the proportion of cyclists stopping before the ASL Entrance?	✓	✗
	Lateral stopping position	To what extent did the LLCS affect the lateral stopping position? i.e. what position did they take in the ASL (Left Zone / Middle Zone / Right Zone)?	✓	✗
Car drivers, motorcyclists and HGV drivers	Longitudinal stopping position	To what extent did the LLCS affect whether other road users encroached into the ASL? How did this vary by when there were some or no cyclists?	✓	✗

In the cycle trial, two types of compliance were studied: Section 3.4.1 assesses to what extent cyclists went through the junction whilst a red signal was still showing; Section 3.4.3 assesses the stopping position of cyclists relative to the main stop line. For other road users, the stopping position relative to the first stop line was analysed, i.e. their compliance with the ASL Entrance.

3.4.1 Compliance with red signals

Cyclists, car drivers, motorcyclists and HGV drivers approached the junction whilst the red signals were displayed. Therefore, non-compliance with the signals would be mainly through participants entering into the junction whilst a red signal was still showing.

Table 9 shows the number of observations where a participant cyclist went through the junction while the signal was still on red, split by whether the LLCS were covered or uncovered. This excludes scenarios where two cyclist participants were released at the same time. A non-compliant observation was defined as where they entered the junction on a red signal[10] and then proceeded through the junction without stopping.

Table 9 – Cycle trial: number of observations where the cyclists were non-compliant with a red signal (video data)

Scenario	Non-compliant observations	Total observations	Percentage non-compliant
LLCS covered	14	838	1.7%
LLCS uncovered	1	910	0.1%

3.4.2 There was a small, but statistically significant, reduction in the percentage of cyclists proceeding through the junction during the red signal with the LLCS: 1.7% when covered to 0.1% when uncovered[11]. The implication is that the cyclists were less likely to go through the junction on a red signal with the LLCS. The 15 non-compliant observations were made by seven participants: two participants each accounted for four of the observations; one participant accounted for three of the observations; four participants went through on red only once. The non-compliant observations were evenly spread across each of the four junction approaches, with most being on left turns.Lateral stopping position

The position that participants stopped at the traffic lights was captured from videos, as discussed in Section 2.6.2. This included the lateral position (i.e. 'Left Zone', 'Middle Zone' or 'Right Zone') and the longitudinal position (i.e. the position along the road).

Figure 15 shows the lateral stopping position of cyclists, by arm and turning movement. This excludes the scenarios where two cyclists were released at the same time. This also excludes the observations where participants entered the junction whilst the signals were red.

[10] i.e. passed "Timing Point 4 (TP4)", 1.7 metres after the main stop line, before the signals changed from red

[11] Using the two proportion Z-test, gives Z= 3.53; i.e. $p<0.001$

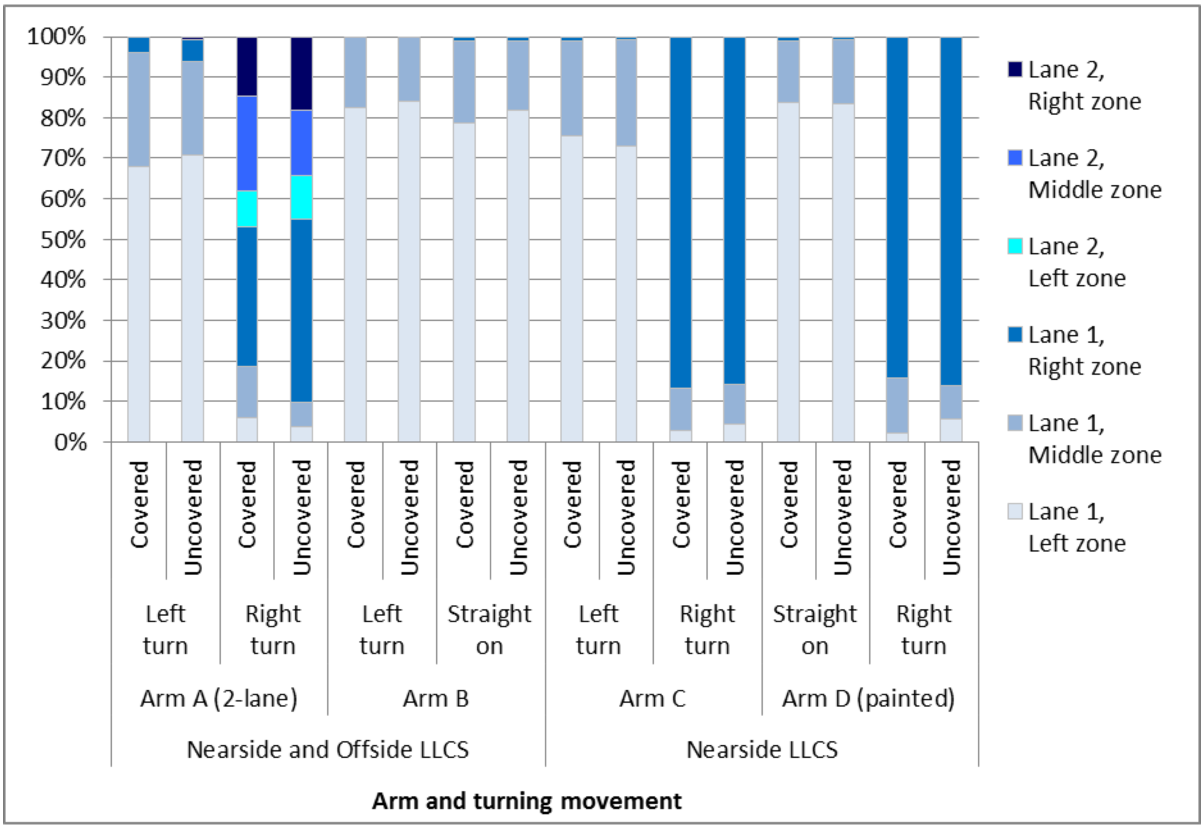

Figure 15 – Cycle trial: lateral position in lane by junction layout, turning movement and LLCS scenario (video data)

Between 70% and 80% of cyclists stopped in the Left Zone when turning left or going straight on, with the remainder typically stopping in the Middle Zone.

For right-turning cyclists on Arm C and Arm D approximately 85% stopped in the Right Zone. Arm A was a two-lane one-way street, with 'Lane 1' being for left and straight on movements and 'Lane 2' for right turns. For right-turning cyclists on Arm A, just over half of right-turning cyclists stopped in Lane 1, which was higher than expected. In the post-trial questionnaire, when asked to explain how easy they thought this turning movement was, some said that they were confused by the road layout being a two-lane one-way street and the approach being on a bend, whereas others said they consciously positioned themselves in the middle of the road.

> *"In a real situation there could be a car on either side, so positioned myself in the middle of the road."*

> *"I only saw the arrows on the road as I turned the corner and then had to cross into the other carriageway to make a right turn."*

Across all arms and turning movements, there were no significant differences between the covered and uncovered scenarios, i.e. there was no evidence to suggest that the LLCS affected the lateral stopping position of the cyclists.

As described in Figure 6 in Section 2.2.3, there was an additional off-side LLCS on Arm A and Arm B. The additional off-side LLCS had no effect on the lateral stopping position of cyclists going straight on, with there being no difference between Arm B and Arm D in the uncovered scenario. It was not appropriate to compare right turners for the approaches with and without the off-side LLCS, because Arm A (near-side and off-side

LLCS) was a two-lane approach, whereas Arm C and Arm D (only near-side LLCS) were both one-lane approaches.

In the motorcycle trial, most motorcyclists stopped in the Middle Zone when turning left or going straight on, whereas most right-turners stopped in the Right Zone. There was no consistent trend in the difference between the covered and uncovered scenarios for the different junction approaches.

3.4.3 Longitudinal stopping position

In the cycle trial, for most of the scenarios, 90% to 95% of cyclists stopped within the ASL. Across all scenarios, there were only very few (0.5%) who stopped before the ASL entrance. Typically 5% to 10% stopped with their front wheel just over the stop line, with hardly any (0.5%) stopping more than one metre past the stop line. There was no consistent trend between the covered and uncovered situations and all the differences were small. The only statistically significant change was a decrease in the proportion of cyclists who stopped past the stop line when the LLCS were uncovered for left turners on Arm A. However this was only significant at the 90% level and so is only indicative of an effect.

In the car trial, in some sessions a controlled cyclist was released 10 seconds ahead of the participant car driver and in other sessions there were no cyclists. Pooling all scenarios without controlled cyclists, 94% of car drivers stopped before the ASL Entrance in both the covered and uncovered scenarios. This proportion was 98% in scenarios with the controlled cyclists ahead, although again there was no difference between the covered and uncovered scenarios. Car drivers were more compliant with the ASL compared to real-world observations (see Section 1.2.4); this is likely due to the limitations of the trial (see Section 2.7). However, despite this limitation, the trial was sufficient to conclude that the LLCS had no effect on stopping position, because there was no difference in the uncovered scenario, relative to the covered scenario.

In the motorcycle trial, about 95% of motorcyclists stopped before the ASL and approximately 5% of participants stopped with their front wheel past the ASL Entrance. There was no statistically significant difference between the covered and uncovered scenarios.

In the HGV trial, the proportion of observations where the participant stopped past the ASL Entrance increased from 3% in the covered scenario to 10% in the uncovered scenario, which was statistically significant. One participant was responsible for the majority (15 out of 17) of the observations, where they stopped past the ASL Entrance. They did so three times towards the end of their first session (covered) and on 12 occasions in their second session (uncovered). In the questionnaire, their answers contradicted their actual behaviour, because they said that they were conscious of the ASL and never stopped inside it. When asked whether the LLCS affected where they stopped, they said “never” and also that the LLCS “reinforced the existence of the cyclist box junction”. This suggests that their actual behaviour was not a due to the LLCS, but may have been more due to a learning effect of the trial.

F4.a. LLCS slightly reduced the percentage of observations where participants went through the junction on a red signal.

F4.b. LLCS did not affect the lateral stopping position of cyclists.

F4.c. For most scenarios, LLCS did not affect the longitudinal stopping position of participants, with the exception of an indicative increase in stop line compliance for left-turning cyclists and a possible increase in HGV drivers encroaching the ASL on the two-lane approach. In the car trial the compliance with the ASL was greater in the scenario where there was a controlled cyclist in front.

Further information in Appendices C & D.

3.5 Did the LLCS affect how people moved off as the signals changed to green?

Table 10 – Research questions on moving behaviour

Road user	Theme	Research question	Video	Q'naire
Cyclists	Reaction to the LLCS	'Reaction Time' – To what extent did cyclists react to the LLCS?	✓	✗
	Time to enter the junction	'Entry Time' – To what extent did cyclists enter the junction ahead of cars?	✓	✗
Car drivers, motorcyclists and HGV drivers	Reaction to the LLCS	'Reaction Time' – To what extent did other road users start moving forwards early? How did this vary by when there were some or no cyclists?	✓	✗
	Delay to enter the junction	'Entry Time' – To what extent were other road users delayed from the green light to reaching the junction entrance?	✓	✗

The times when participants started to move ('Reaction Time'), entered the junction ('Entry Time'), and cleared the junction ('Clearance Time') were recorded as explained in Section 2.6.2.1. In this section results are presented for the Reaction Time and Entry Time.

In the cycle trial, participants encountered the junction both with and without a controlled car; similarly in the car trial, participants encountered the junction both with and without a controlled cyclist. In both the cycle trial and car trial, the cyclist always approached the junction ahead of the car. Analysis is presented in this section only for the sessions with the additional controlled cyclists/cars.

3.5.1 Reaction Time

Figure 16 shows the Reaction Time of the participants to the LLCS in both the cycle trial and the car trial, for both the covered (dotted line) and uncovered (full line) scenarios. The data was pooled across all turning movements and junction approaches.

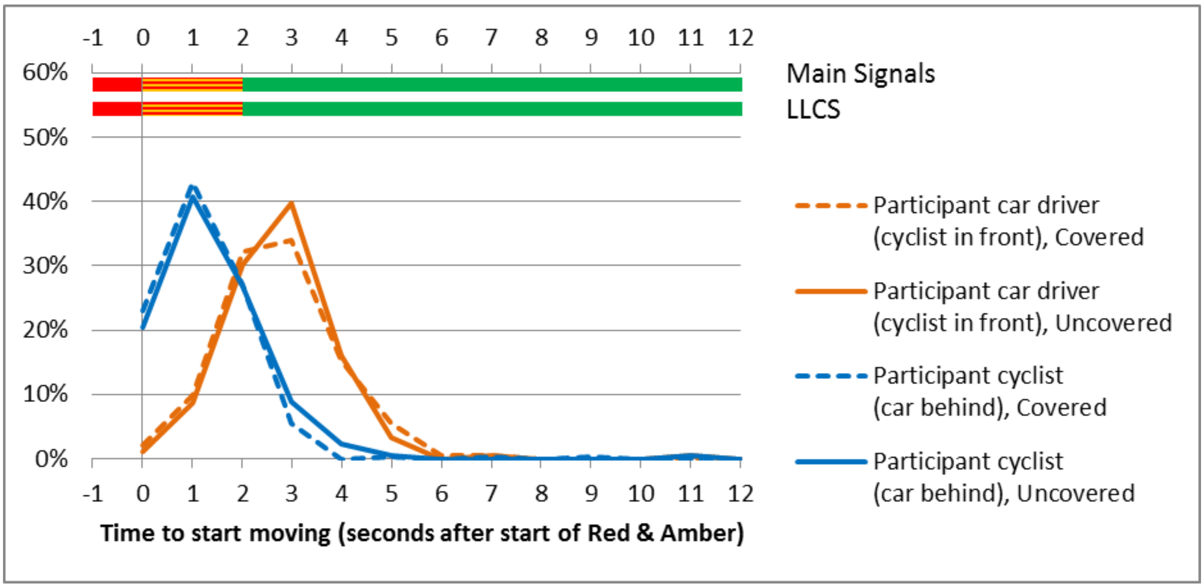

Figure 16 – Cycle trial and car trial: Reaction Time of cyclists and car drivers, by LLCS scenario (video data)

This shows that in both the cycle trial and the car trial, there was no difference in Reaction Time between the covered and uncovered scenarios. In other words, the LLCS had no effect on when the participants started moving. This is as might be expected, because the LLCS changed at the same time as the main signals. This also shows that typically the cyclists started moving before the car driver, which is as expected, given that in all scenarios the cyclist was in front of the car.

When the LLCS were uncovered, there were small statistically significant increases in cyclists' Reaction Time in two out of 16 statistical tests, for left turners from Arm B and right turners from Arm C, both in scenarios with a car behind[12]. In the car trial, in 12 out of 14 statistical tests[13], there were small statistically significant increases in Reaction Time for right turners from Arm A, for scenarios both with and without cyclists in front. However, for the most part, there were no differences between the covered and uncovered scenarios.

3.5.2 Entry Time

Figure 17 shows the Entry Time for cyclist and car driver participants into the junction with (full line) and without (dotted line) LLCS. In this graph, observations have been excluded where the participant entered into the junction during the red signal[14]; i.e. where the Entry Time was negative.

[12] 16 t tests were conducted for the cycle trial (two turning movements from four arms, with and without a car behind)

[13] No left turn from Arm A, so two fewer t tests than the cycle trial

[14] See Section 3.4

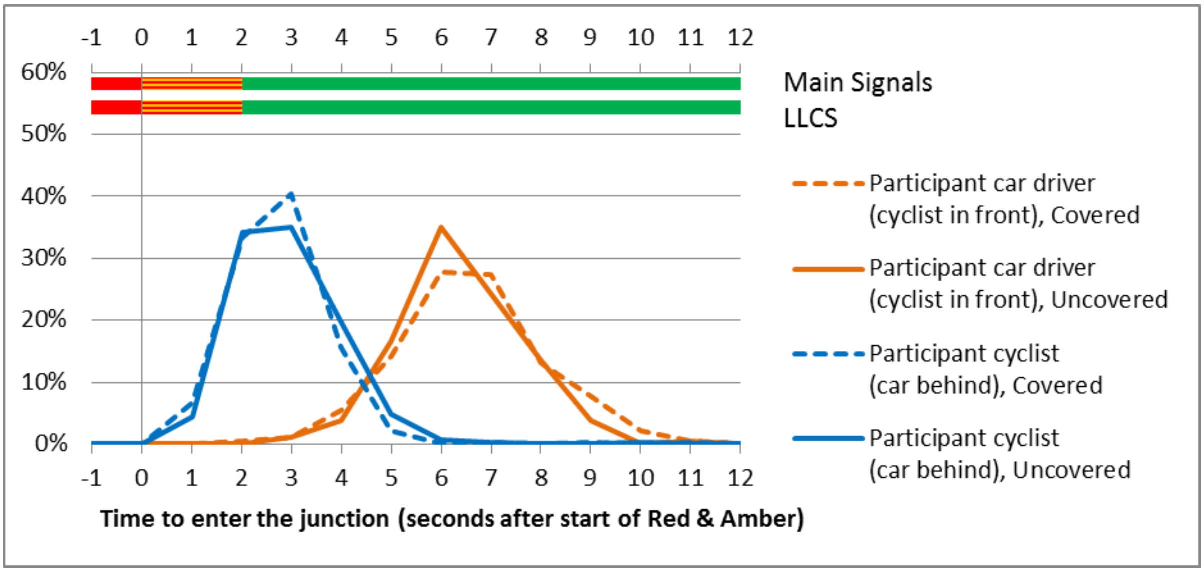

Figure 17 – Cycle trial and car trial: Entry Time of cyclists and car drivers, by LLCS scenario (video data)

Similar to the Reaction Time, pooling all turning movements and junction approaches, there was no difference in Entry Time between the covered and uncovered scenarios, i.e. the LLCS had no discernible effect on when participants entered the junction.

In the cycle trial, there was a statistically significant change in one out of the 16 statistical tests, with a small increase in Entry Time for right-turning cyclists on Arm C from the covered to the uncovered scenario. In the car trial, there were no statistically significant changes in Entry Time between the covered and uncovered scenarios in 14 statistical tests.

Figure 18 shows that in the scenario where there was a cyclist in front of the participant car driver, the average Entry Time was approximately one second greater than the scenario without the controlled cyclist. This may suggest that car drivers had to wait for the cyclist in front before they could enter the junction.

On average it took approximately 3 seconds for the cyclists and 6 seconds for the car drivers to enter the junction. This difference between the cyclists and the car drivers was because the cyclists were always positioned in front of the cars, and therefore entered the junction first.

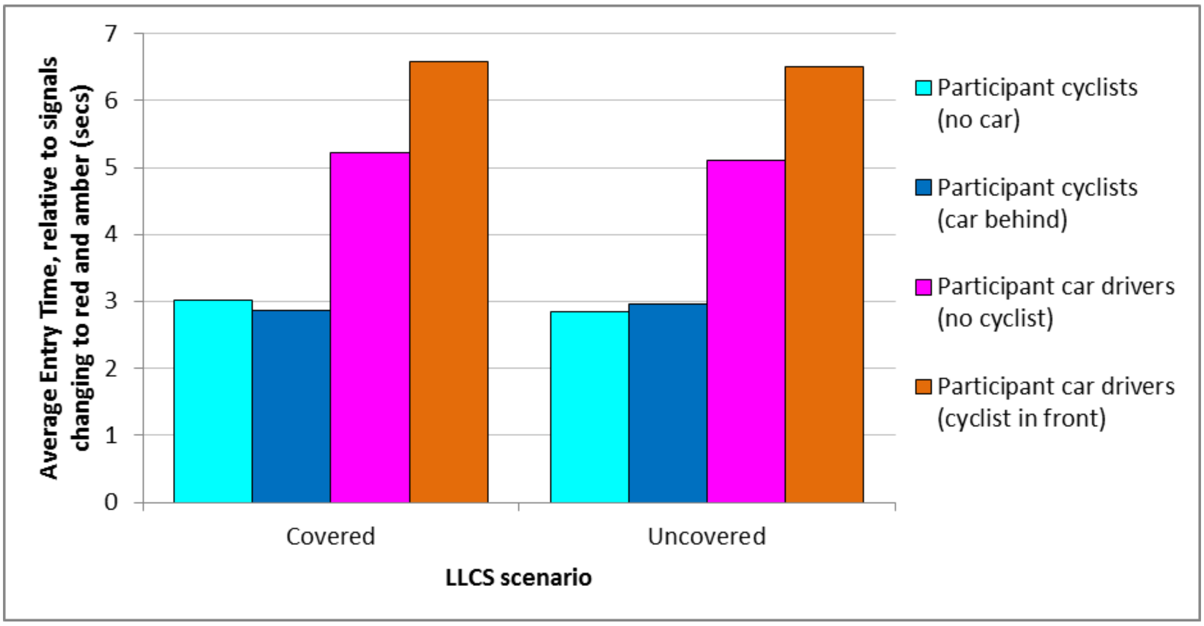

Figure 18 – Cycle trial and car trial: average Entry Time of cyclists and car drivers, by participant group and LLCS scenario (video data)

3.5.3 Speed through the junction

The distance of each turning movement was divided by the average time taken to pass through the junction, giving a measure of 'average speed', as shown in Figure 19.

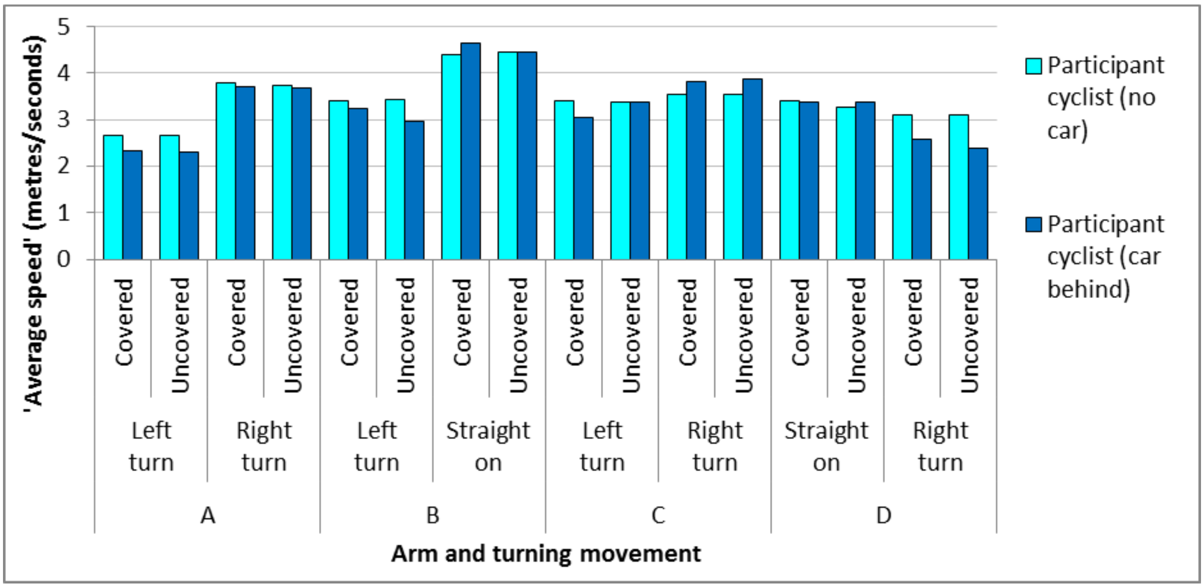

Figure 19 – Cycle trial: average speed, turning movement and LLCS scenario (video data)

The turning movement with the largest average speed was straight on from Arm B, which may be explained by the fact that it was a downhill straight-on movement. The turning movement with the lowest average speed was the left turn from Arm A, possibly explained by the tight turning radius between Arm A and Arm B. Right turners from Arm D also had low average speeds; this was the only turning movement where there was a conflict with oncoming traffic. This turning movement also had large variance due to a few observations where the participant passed the Junction Entrance and waited for the Indicative Green Arrow. All other turning movements averaged between 3m/s and 4m/s. The observed speeds were lower than the standard value of 5.4m/s (12mph[15]). This may have been because the cyclists were not fully up to cruising speed and were also turning through the junction. This may also be partially explained by a proportion of the participant sample being infrequent cyclists (see Appendix D).

F5.a. LLCS did not affect when cyclists and car drivers started moving or entered the junction, although the car drivers were delayed entering the junction by approximately one second in the scenario with a cyclist in front.

3.6 Did the LLCS affect perceived safety?

Table 11 – Research questions on safety

Road user	Theme	Research question	Video	Q'naire
Cyclists	Time to clear conflict zone	'Clearance Time' – To what extent did the LLCS prioritise cyclists to remove potential conflict points mid-junction between cyclists and motorised vehicles?	✓	✗
	Right turning cyclists	To what extent did right-turners from Arm D turn ahead of oncoming cars?	✓	✓
All road users	Trial experiences	What was the effect on the perceived safety?	✗	✓
Pedestrians and partially sighted pedestrians	Reaction to LLCS	To what extent did the LLCS affect where pedestrians started crossing? / What effect did the LLCS have on whether pedestrians walk into the ASL when walking up to the signals?	✓	✗
	Compliance with Red Man	To what extent did it affect compliance with the Red Man?	✓	✓
	Trial experiences	Are there reasons to not mount LLCS on each of the following: - A normal pedestrian crossing - A near-side pedestrian crossing - A crossing at a signalised junction with no pedestrian signals?	✗	✓

3.6.1 Cycle clearance times

The times for clearing the junction by the participant car drivers and cyclists were similarly uniform with and without the LLCS; i.e. there was no difference in the Clearance Time between the covered and uncovered scenarios. In the cycle trial, there was a statistically significant change in one out of the 16 statistical tests, with a small increase in Clearance Time for left-turning cyclists with a controlled car on Arm B from the covered to the uncovered scenario. In the car trial, there were no statistically significant changes in Clearance Time between the covered and uncovered scenarios in 14 statistical tests.

[15] "The average speed of cyclists on a level surface is around 12 mph", source: DfT guidance LTN2/08, §8.2.2

Similar to the Entry Time, in the car trial the Clearance Time was lower for the scenarios where there was no controlled cyclist in front.

3.6.2 Right-turning in front of cars from opposing direction

As discussed in Section 2.1, the signals on Arm B and Arm D changed to green at the same time. Table 12 shows the number of observations where the cyclist turned right from Arm D in front of the car going straight on from Arm B. There was only one observation where this occurred, which was in a covered scenario and so was not due to the introduction of the LLCS. The measurements from the uncovered scenario will form the baseline for future trials.

Table 12 – Cycle trial: proportion of observations where cyclists turned right in front of cars from opposite approach, by participant group and LLCS scenario (video data)

Participant group	Scenario	No	Yes	Sample size
Participant cyclist (car behind)	Covered	97.6%	2.4%	41
	Uncovered	100.0%	0.0%	49
Two participant cyclists (car behind)	Uncovered	100.0%	0.0%	29

3.6.3 What was the effect on perceived safety?

Participants were asked "How safe is it… to use this type of junction compared with an ordinary junction with traffic signals?". Each type of road user was asked about safety for their own road user group. The LLCS were not explicitly mentioned in the question, because the same question would also be used for future trials, where larger ASLs would also be one of the design variables, enabling a direct comparison to be made between responses to different trials.

The participant sample consisted largely of residents of the Wokingham/Bracknell area, where few junctions have ASLs. As such many of the comments represent the participant's perception of the safety of the trial junction, with ASLs, in comparison with an "ordinary" signal junction [without an ASL]. Comments that did not specifically mention LLCS were filtered out of the analysis in this section.

3.6.3.1 Cyclists

About 40% of cyclists gave comments specifically about the LLCS, while about 20% focused on the safety impacts of ASLs. Of the cyclists who mentioned LLCS, none said that junction was more unsafe, about half said the junction was either safer or much safer, with the remainder saying that the junction was neither safer nor more unsafe, see Figure 20.

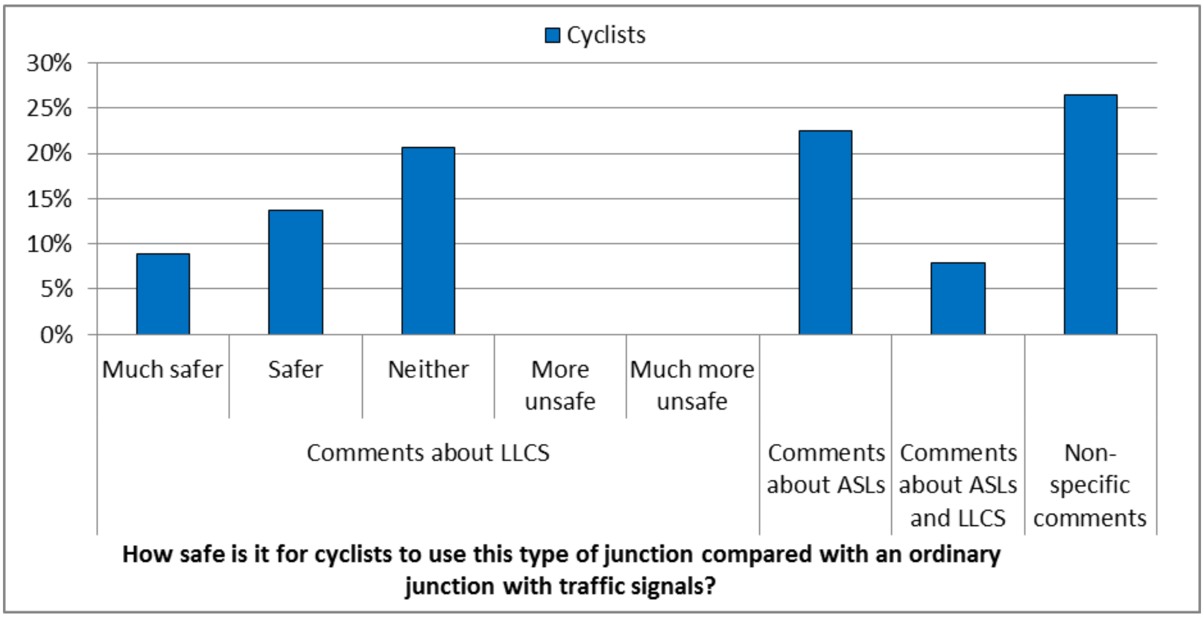

Figure 20 – Cycle trial: proportion of cyclists who thought the junction was safer or more unsafe due to the LLCS (questionnaire)

The comments about LLCS from the cyclists were classified as shown in Figure 21.

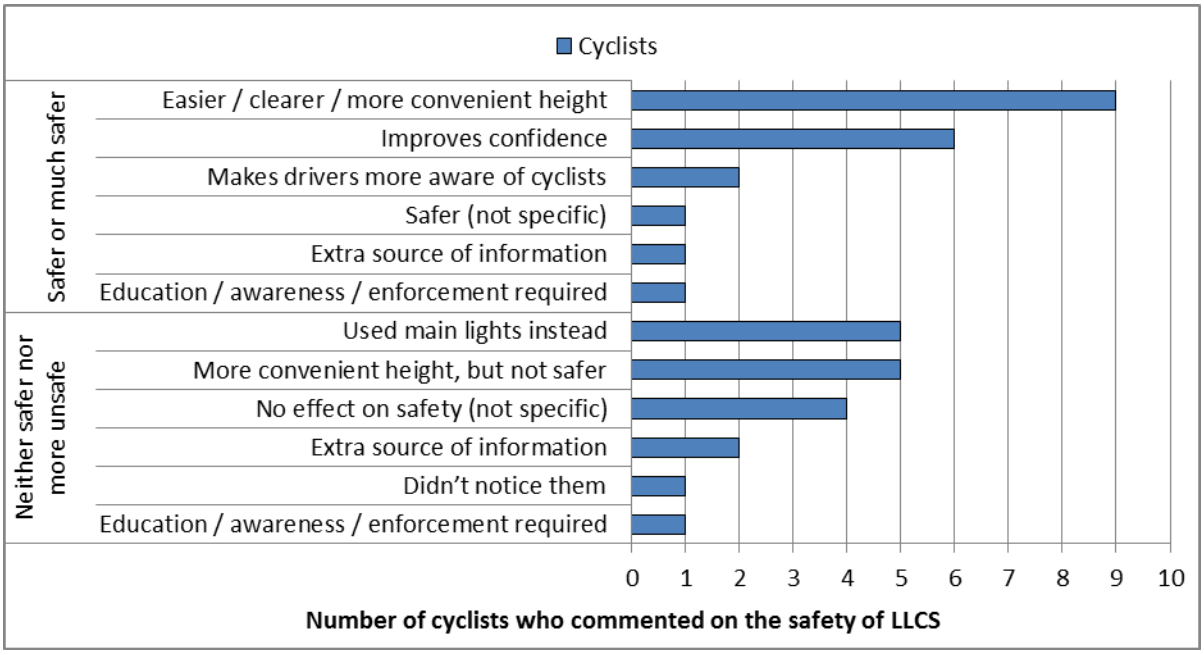

Figure 21 – Cycle trial: comments from cyclists who thought the junction was safer or more unsafe due to the LLCS (questionnaire)

Of those cyclists that said LLCS had a positive impact on safety, most said it was because they provided clearer information at a convenient height. Some said that LLCS made them feel more confident, while two of the cyclists suggested that LLCS may make drivers more aware of cyclists.

> *"It is clear when you can go or have to stop." (Cyclist)*

> *"Lights made me feel safer as allowed me to feel less pressured by motorists." (Cyclist)*

"I think they give the message to car drivers that you have the right to be there." (Cyclist)

Of those cyclists that said LLCS would have no effect on safety, most said that this was because they didn't use the LLCS and used the main signals instead. Other cyclists said that they did find the LLCS useful, but they didn't think that there would be any difference to safety.

"Ordinary traffic signals are clearly visible, extra lights do not improve safety as most road users look for the main lights automatically." (Cyclist)

"I don't think it affects safety, it just makes it easier to look at." (Cyclist)

3.6.3.2 Other road users

Similar to the cyclists, about 40% of car drivers gave comments specifically about LLCS when asked about the safety of the junction, see Figure 22. Of these, most said that the LLCS had no effect on safety, with about a quarter saying it was safer for them and about a fifth saying it was more unsafe.

About 60% of motorcyclists commented on the safety impacts of the LLCS; of these about a quarter said the impacts were positive and a quarter said the impacts were negative.

When asked about the safety of the junction, most pedestrians talked about the LLCS and not the ASLs. None said that the junction was more unsafe for pedestrians because of the introduction of LLCS, while most thought that they didn't affect pedestrians.

The majority of the comments from HGV drivers were not specific enough to mention LLCS.

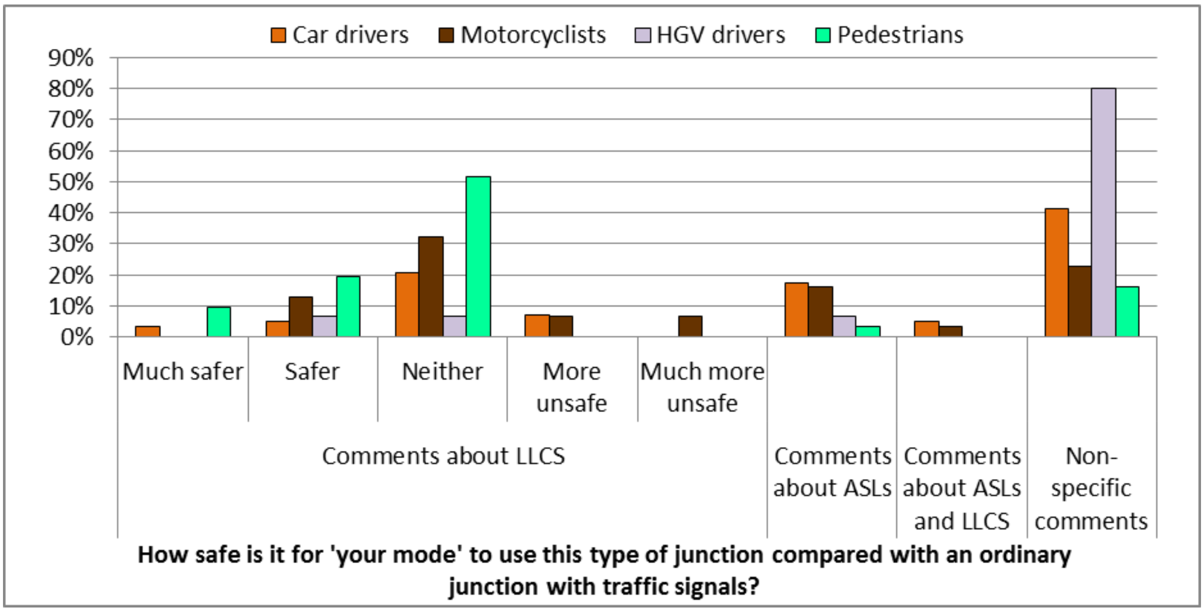

Figure 22 – Car trial, motorcycle trial, HGV trial, pedestrian trial: proportion who thought the junction was safer or more unsafe for them due to the LLCS (questionnaire)

The comments about the safety impacts of LLCS from the other road users were classified as shown in Figure 23.

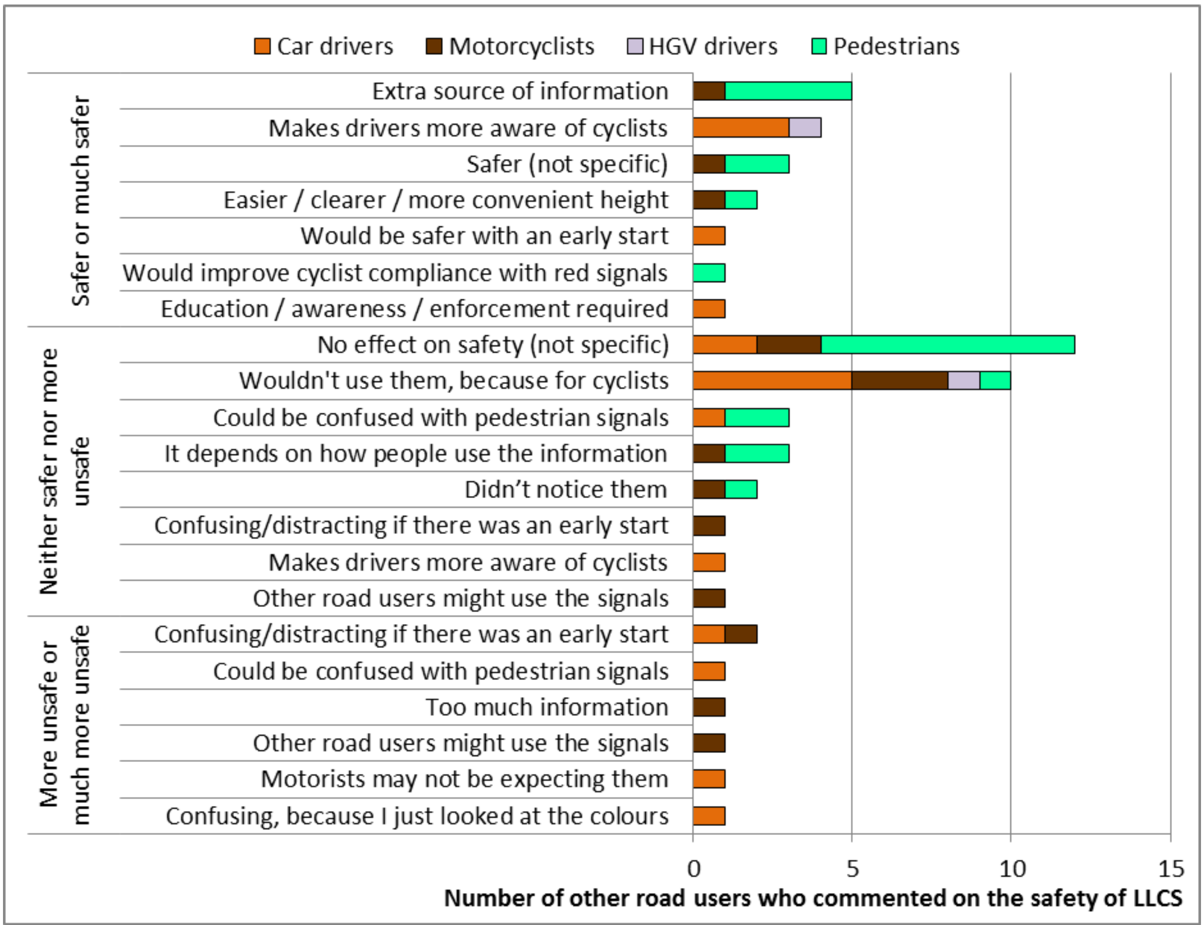

Figure 23 – Car trial, motorcycle trial, HGV trial, pedestrian trial: comments on whether the junction was safer or more unsafe due to the LLCS (questionnaire)

Of those who said LLCS had a positive impact on safety for them, some said that this was because they found the extra information useful, while others said it made them more aware of cyclists.

> *"Safer as you have more information about the road." (Pedestrian)*

> *"Better awareness generated by cyclist and centre signals." (HGV driver)*

Of those who said LLCS would not have an impact on safety for them, most said this was because the signals didn't affect them. Some mentioned that they realised the LLCS were for cyclists, but they would continue to use their own signals. Some suggested that the LLCS might be confused with pedestrian signals, but they didn't consider this be more unsafe.

> *"I didn't see much difference [from the] pedestrian's point of view." (Pedestrian)*

> *"Treated as normal junction, noticed low level signal but assumed they were for cyclists." (Motorcyclist)*

> *"Seeing a green cycle symbol at the three aspects at the same level as the pedestrian could be taken as applying to a pedestrian. I made this mistake once (not paying proper attention)." (Pedestrian)*

Of the few car drivers and motorcyclists who thought the LLCS made the junction more unsafe, reasons given included confusion, distraction, too much information and other road users using the signals.

"Marginally unsafe, it they change at different times or cause confusion." (Car driver)

"Increased complexity increases risk. There are already too many items to register." (Motorcyclist)

"May lead to confusion for some motorcyclists who may think they can go on this signal." (Motorcyclist)

3.6.4 Pedestrian crossing behaviour: where they crossed

In the pedestrian trial, data was captured on when participants arrived at the crossing, when they crossed and where they crossed. Participants were released in pairs 15 metres 'upstream' of the crossing, so that they saw the LLCS on approach. They were also released up to the Puffin crossing from the 'downstream' side, so that they saw the low level near-side pedestrian signals on approach. Figure 24 shows where the pedestrians stepped into the road for the six different types of crossing.

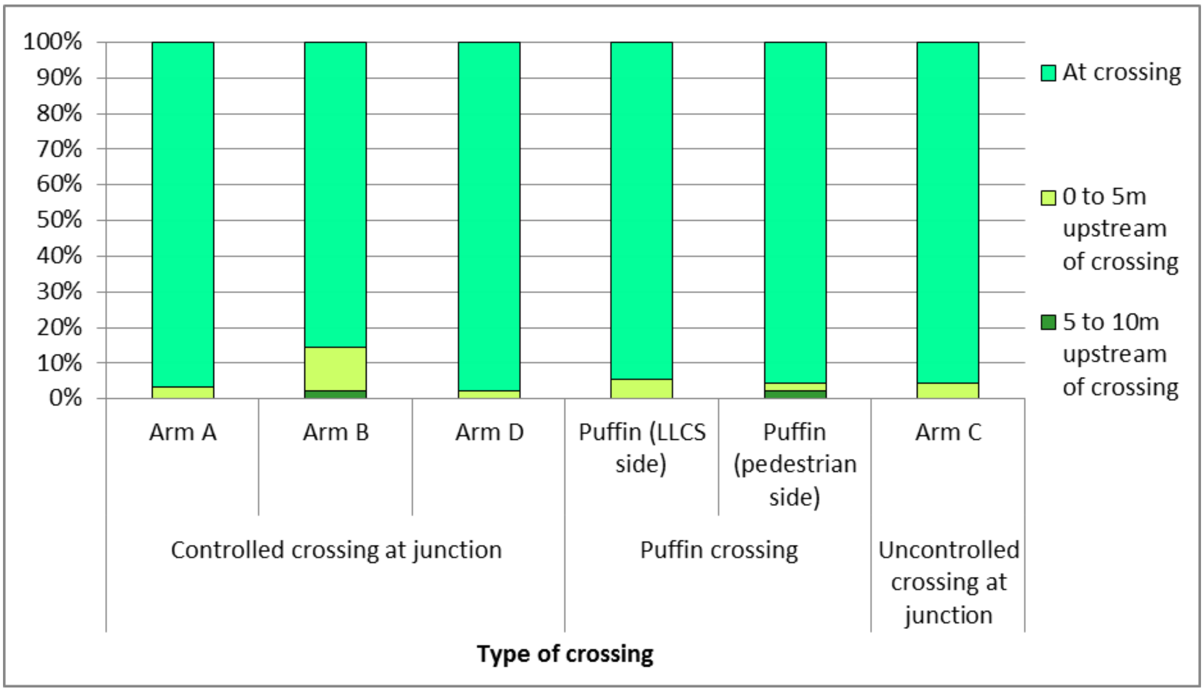

Figure 24 – Pedestrian trial: zone where pedestrians started to cross, by crossing type (video data)

For most layouts, about 95% of participants stepped into the road 'at the crossing', i.e. at the dropped kerb. In contrast, about 15% 'cut the corner' on Arm B by stepping out into the road up to 5m before the crossing, i.e. in the ASL. This may be explained by the fact that this crossing had an island half way across. For the most part, about 80% to 95% reached the other side of the road whilst still at the crossing.

3.6.5 Pedestrian crossing behaviour: compliance with Red Man

Figure 25 illustrates which pedestrian signal was showing when participants started to cross, filtered for those who arrived on a Red Man.

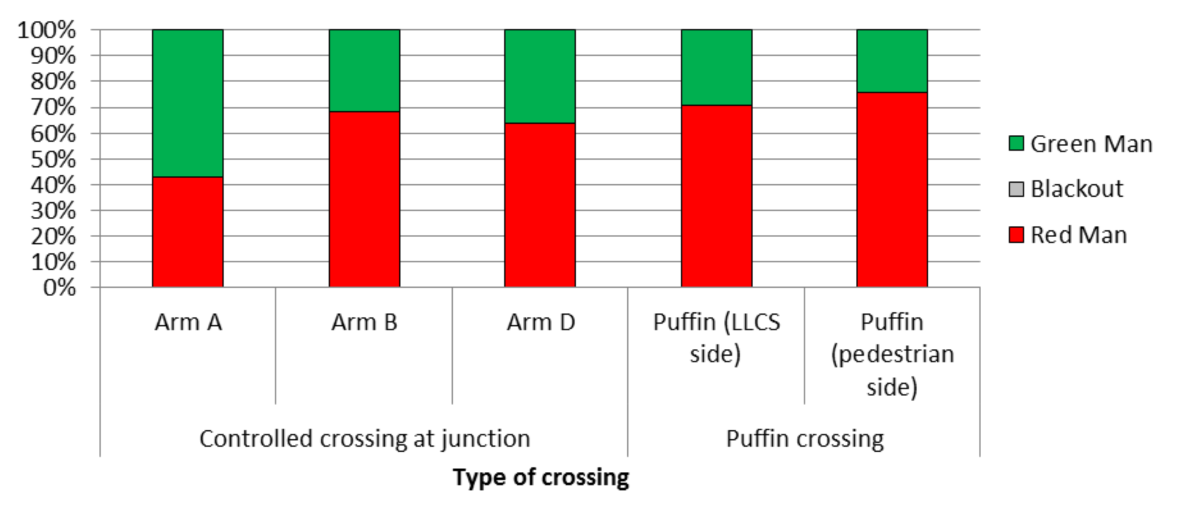

Figure 25 - Pedestrian trial: signal showing when pedestrians started to cross (for those who arrived on a Red Man), by crossing type (video data)

This shows that for most crossing types, about a third of pedestrians waited for the Green Man, whereas about two-thirds crossed soon after they arrived, i.e. with the Red Man showing. The crossing on Arm A was a one-way street and so the pedestrian signals showed a Green Man more often than on other crossings, i.e. whenever the traffic signals were red. For Arm A, a higher proportion of pedestrians crossed on the Green Man compared to other crossings, which may be explained by the shorter wait for the Green Man in this scenario.

F6.a. Of the cyclists who commented on the safety impacts of LLCS, none said that junction was more unsafe, about half said the junction was either safer or much safer.

F6.b. Of the cyclists that said LLCS had a positive impact on safety, most said it was because they provided clearer information at a convenient height. Some said that LLCS made them feel more confident and some suggested that LLCS may make drivers more aware of cyclists.

F6.c. Of the other road users who commented on the safety impacts of LLCS, about a quarter of motorcyclists and a quarter of car drivers said the impacts were positive, whereas a quarter of motorcyclists and a fifth of car drivers said the impacts were negative. Most pedestrians thought that LLCS had no effect on them, and none said that the junction was more unsafe.

F6.d. Of the other road users who said LLCS had a positive impact on safety for them, some said that this was because they found the extra information useful, while others said it made them more aware of cyclists. Of the few car drivers and motorcyclists who thought the LLCS made the junction more unsafe, reasons given included confusion, distraction, too much information and the potential for other road users using the signals.

Further information in Appendix D.

4 Conclusions

4.1 Findings against each research question

Section 3 contains the findings from the trial of LLCS used as repeaters of the main traffic signals with no early release (trial code: 'M14'), compared against a Control scenario where the cycle signals were covered. The key findings are summarised at the end of each sub-section in Section 3. Each finding has an ID (e.g. "F1.a"), where the number relates to a corresponding research question as defined in Section 2.5; these findings are referenced in this section below. These key findings are also summarised in a table in Appendix A.

In summary:

1. Generally, the LLCS were well understood (75% to 95% across the different road user groups) [F1.a]. There was only a minor concern that a small percentage of pedestrians, cyclists and car drivers interpreted them as pedestrian crossing signals, potentially as Toucan crossing signals [F1.b]. All the partially sighted pedestrians understood that they were not for them [F1.c].
2. Most road users (at least 80%) considered that cyclists would benefit from LLCS [F2.a]. About 80% of cyclists were in favour of them, and over 90% of most other road user groups (excluding motorcyclists) were not negative towards them [F2.b].
3. Suggestions for improvements included to make the signals bigger and more obvious and also to provide an early release [F2.c]; about three-quarters of the cyclists said that the height and angle was 'about right' [F2.d].
4. Most cyclists used them as an extra source of information [F3.a]; in particular whilst they typically used the main signals on their approach to the junction, 70 to 80% of cyclists used the LLCS whilst waiting to turn left [F3.a]. At the uncontrolled crossing, about half of the pedestrians said that they used the LLCS, with approximately 10% stating they were the most important factor when deciding to cross [F3.b].
5. The LLCS did not adversely affect compliance at the junction. There was a slight reduction in the percentage of cyclists who went through the junction on a red signal [F4.a]. The stopping position of participants was largely unaffected, although there were some small variations in some scenarios [], [F4.c]. The times car drivers and cyclists started moving and entered the junction were also unaffected [F5.a].
6. No cyclists said that junction felt more unsafe with the LLCS and about half said the junction was either safer or much safer [F6.a]; LLCS were perceived to provide clearer information at a convenient height, made some cyclists feel more confident, while others suggested that LLCS may make drivers more aware of cyclists [F6.b].
7. About a quarter of motorcyclists and a quarter of car drivers said the safety impacts were positive, with some saying that they found the extra information useful, while others said it made them more aware of cyclists. A similar proportion of motorcyclists and car drivers said there were negative impacts on safety due to the LLCS, giving reasons including confusion, distraction, too much

information and the potential for other road users using the signals. Most pedestrians thought that LLCS had no effect on them, and none said that the junction was more unsafe [F6.c], [F6.d].

4.2 How the findings relate to the study objectives

The main study objective was to gather evaluation evidence on LLCS used as repeaters of the main traffic signals in the context of an application to the DfT for an experimental order for an on-street trial.

The evidence from this trial supports the progression to on-street trialling of LLCS as repeaters on the same poles as the main traffic signals. The evidence suggests that the system would be quickly understood by nearly all road users, would not adversely affect safety and could offer a benefit to cyclists as a convenient source of information. The only caveat is that a small number of pedestrians misinterpreted the meaning of the signals to be for cyclists crossing the road. It is probable that pedestrians would correctly interpret them in the context of on-street applications; however, some monitoring of behaviour to confirm this would be advisable. In particular there may be concerns if LLCS are to be installed on sites where there is an uncontrolled pedestrian crossing at the junction or there is a Toucan crossing. In these instances greater care would need to be taken in the design specific to each implementation. Public information and awareness campaigns associated with the introduction of LLCS on-street would also help to reduce potential misunderstandings of their purpose.

As discussed in Section 1.1, this report ("M14") is the first of four reports into a series of off-street trials of Low Level Cycle Signals. This trial provided a baseline for further trials in which the LLCS: had an 'early release' ("M18"); were on a separate pole ("M19"); and were accompanied by deeper cycle reservoirs ("M24").

There were two findings from this trial related to the concept of the LLCS changing to green before the main signals. Some cyclists suggested that an early release would provide additional benefits to cyclists (Figure 13). Some motorcyclists indicated that they would consider using an early release in some situations (see Appendix D); following this finding, it was decided to include a motorcycle trial as part of the "M18" trial.

References

(Allen et al. 2005)
Allen, D., Bygrave, S., & Harper, H. (2005) *Behaviour at Cycle Advanced Stop Lines* – (PPR240). Crowthorne: Transport Research Laboratory.

(Alrutz 2013)
Signale für den radverkehr, Ein Leitfaden zur Radverkehrssignalisierung, Aktualisierte 2. Auflage 2013. Stadt Muenster

(Atkins 2005)
Advanced Stop Line Variations Research Study Research Findings. Atkins

(Ball et al. 2014)
Ball, S. D., Hopkin, J., Reeves, C., Gardner, R., Knight, P., & and York I (2014) *High level signals with a red cycle aspect, Track trial report* - (PPR715). Crowthorne: Transport Research Laboratory.

(DfT 2003)
Traffic signs manual, Chapter 5, road markings. DfT

(Johnson et al. 2010)
Johnson, M. et al. *Riding through red lights: The rate, characteristics and risk factors of non-compliant urban commuter cyclists* Accident Analysis and Prevention 43 (2011) 323–328

(RiLSA 1992)
RiLSA - *Guidelines for Traffic Signals - English Version of RiLSA with minor Modifications*.

(TfL 2007)
Proportion of Cyclists Who Violate Red Lights in London. RNPR Traffic Note 8

(TSRGD 2002)
Traffic Signs Regulations and General Directions

(assets.dft.gov.uk 2013)
Road Traffic Regulation Act 1984 – Sections 64 and 65, Special Directions. GT50/139/0092. DfT. http://assets.dft.gov.uk/trafficauths/case-3826.pdf

(www.gov.uk 2013)
Speech by Robert Goodwill MP. *Cycling networks fit for growth*. Published 06/12/2013. https://www.gov.uk/government/speeches/cycling-networks-fit-for-growth

(www.government.nl 2013)
Road Traffic Signs and Regulations in the Netherlands

(www.tfl.gov.uk 2013)
TfL and its policing partners step up enforcement of 'bike boxes' to help improve cycle safety in the Capital. TfL http://www.tfl.gov.uk/corporate/media/newscentre/28403.aspx