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Trials of segregation set-back at side roads

Overview report and recommendations

York, I., Chesterton V., and Benton M.

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S Greenshields (Project Manager)

M Jones (Technical Referee)

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Executive Summary

This report provides an overview and interpretation of the key findings from four trials carried out by TRL on behalf of Transport for London (TfL) to investigate the effects of 'setting-back' a kerb-segregated cycle track at different distances from a side-road junction.

The trials discussed in this report comprised three trials on TRL's closed Small Roads Network, and one in TRL's DigiCar driving simulator. Full details of each trial and the results obtained are provided in the individual trial reports that are available as technical Annexes[1].

A review of existing international guidance and research on approaches for taking cycle lanes across side-roads identified two distinct design strategies. Either:

- Cyclists are returned to the carriageway level at least 20m before the junction, so as to establish their presence in the traffic, or
- Segregation is brought right up to the junction (typically <=5m) and very tight geometry (and often raised crossings) used to keep turning speeds down and encourage vehicles to cross the cycle lane at close to 90 degrees.

However, little evidence to support these approaches was identified. Furthermore, when comparing practices in other countries it is important to be aware of important contextual differences, in particular different priority rules for vehicles crossing adjacent cycle tracks in countries such as Denmark and the Netherlands. Therefore, a programme of trials was implemented with the aim to investigate how different segregation set-back distances affects the behaviour of drivers and cyclists under UK trial conditions, and so gain a better understanding of the implications for implementing different set-back distances on road. The overall objectives were:

- What set-back distance minimises the risk of conflict between all road users?
- What set-back distance is the most appealing and preferred by the different road users?

This report provides a summary of the methodology used for each trial and their key findings, followed by a comparison of the results, taking account of differences between the trial methodologies. The report focuses on four elements of the findings. These relate to user:

- Speed
- In lane position
- Stopping position
- Qualitative responses

The video observations for the three test track trials all consistently showed that the segregation set-back distance had little impact on car drivers' speed and turning path, until it was within 5m of the junction. When the kerb is sufficiently close to the junction

[1] Annexes available from: www.trl.co.uk/cyclinginnovationtrials

to have the effect of tightening the turning radius, it necessitates drivers turning left, into the side-road, to slow down and can result in them taking a position further away from the kerb. Although the speed reduction observed in the on-track trails was small, it was measured as an average over the final 60m of the drivers' run, so will understate the reduction at the turn. The driver simulator trial found no difference between 20m and 5m set-back distances on speed and position, however the roads in this layout were much wider (two lane), suggesting that the segregation would need to be brought even closer to the junction to have an effect when other aspects of the road layout provide a large turning radius for drivers.

However, the results of the driver simulator trial also showed that the presence of a cyclist at the 'conflict point' had a significant impact on driver speed. That is, when there was a conflicting cyclist present, drivers chose a slower speed. Furthermore, observations of how speed varies with distance from the junction showed that when a conflicting cyclist was present, the drivers slowed down on the approach to the junction to wait for the conflicting cyclist to pass in front on them. Once the cyclist passed in front of the driver the driver increased their speed to make the turn into the side road behind the cyclist. This suggests that, even with the large turning radii available in the simulated layout, drivers still respond to the presence of cyclists at the turning.

A further observation of the track trials was that, with the 5m set-back, left-turning drivers overtaking the cyclist on the approach to the junction gave the cyclist more room when they did so: passing the cyclist at a greater lateral distance, and crossing the cycle lane at an angle closer to the perpendicular. As well as showing that drivers give cyclists more space when the turning geometry is tighter, the changed approach angle involves less encroachment into the cycle lane and gives the drivers improved visibility of approaching cyclists.

Qualitative feedback from questionnaires shows that while drivers tended to favour maximising the extent of segregation on the approach to the junction, cyclists were divided in preferences for short or long set-back distances. The differences reflect different views on the benefits of segregation, including cyclists' concerns about being able to position themselves for passing the junction and that drivers wouldn't give way when turning across their path. Responses from drivers showed some confusion over the meaning of the markings used to continue the cycle lane past the side-road turning, which included triangular markings, and over who had priority.

The findings from the off-street trials suggest that two different strategies can then be considered:

1. Bring segregation very close to the turning (<5m), sufficient to reduce the turning radius and so reduce turning speeds and position turning vehicles at right angles to the path of cyclists (this is similar to the principles behind the use of 'continental geometry' at roundabouts). This approach would be most appropriate where geometry is already tight and vehicle speeds comparably low, or where other measures to achieve this will also be implemented.
2. End the segregation at least 20 m from the junction, giving cyclists sufficient space to re-introduce themselves into the traffic flow and for drivers to adapt to their presence. This would be more suitable where traffic speeds are higher and tight turning geometry is not considered to be appropriate.

The range in between, i.e., >5m to <20m, should be avoided as this can constrain cyclists from re-establishing themselves into the traffic flow while leaving vehicles' turning path and speed unchanged.

Longer set-backs may also be necessary if cyclists need to turn right at a junction, or some other means provided to allow them to leave the segregated lane and position themselves.

Given the qualitative feedback suggesting some confusion over priorities and the interpretation of road markings at the end of the segregated section, which is of particular importance where short set-back distances are used, further consideration (e.g. in on-street trials) should be given to identifying the most effective treatments for establishing cyclist priority at the junction.

It is important to recognise that any off-street trial inevitably has its limitations and it cannot be assumed that the behaviours reported here would be replicated in a real street environment. The findings of this trial should not therefore be regarded as design guidance; further experience from on-street trials will therefore be needed before more definitive design recommendations can be made. As these trials were undertaken on roads with speeds lower than 30mph, it is suggested that any initial on-street trials of the short set-back distances are carried out on roads with similar speeds. Initial trials of short set-back distances should ensure that the set-back distance is sufficiently short, taking account of the geometry of the junction, to restrict the path and speed of turning vehicles to below 20mph (comparable with the off-street trial conditions). Where traffic speeds are higher than those found in the trial (which were typically 20 mph to 30 mph), a precautionary approach would be to consider longer set-backs to give cyclists more time to control their position and for drivers to become aware of them.

1 Introduction

1.1 Background to this report

This report provides an overview and interpretation of the key findings from four trials carried out by TRL to investigate the effects of 'setting-back' a kerb-segregated cycle track[2] at different distances from a side-road junction. The trials were carried out on behalf of Transport for London (TfL) as part of a wider programme of test track and simulator trials of innovative cycling infrastructure to inform the design of future schemes to be delivered under the Mayor's Vision for Cycling.

The trials discussed in this report comprised three trials on TRL's closed Small Roads Network, and one in TRL's DigiCar driving simulator. Full details of each trial and the results obtained are provided in the individual trial reports that are available as technical Annexes[3]. This report begins with a review of existing guidance and research on approaches for taking cycle lanes across side-roads, which provides the background context to the trials. The report then provides a summary of the methodology used for each trial and their key findings, followed by a comparison of the results, taking account of differences between the trial methodologies. The report focuses on four elements of the findings. These relate to user:

- Speed
- In lane position
- Stopping position
- Qualitative responses

The report concludes with a discussion and interpretation of the findings, and draws out some recommendations for future implementation of such schemes, including on-street trials that may be appropriate.

The Annexes[3] to this report are listed below:

- Annex 1 – Review of existing guidance
- Annex 2 – Trial M1 with heavy goods vehicles turning into the side road
- Annex 3 – Trial M2 with car driver and cyclists
- Annex 4 – Trial M4 with car drivers turning into and out of the side road
- Annex 5 – Trial M13 with car drivers using a driving simulator

[2] A note on terminology: the use of physical segregation within the carriageway to create a space for cyclists from which motor vehicles are excluded would normally be considered to create a cycle track. However, in this report and Annexes, the looser term 'segregated cycle lane' is often used, as the same 'lane' includes both segregated and unsegregated sections, with some sections being either segregated or unsegregated at different times.

[3] Annexes available from: www.trl.co.uk/cyclinginnovationtrials

1.2 Review of existing guidance and research literature

This section summarises the findings of the literature review of existing guidance and research. The annex of this document comprises the full review and details the specific documents considered[4].

Although guidance on segregation set-back is limited, especially for the kerb-segregated lanes being considered by TfL, and does not appear to have been based on significant research evidence, two distinct design approaches can be identified. Either:

- **Design approach A:** Cyclists are returned to the carriageway level at least 20m before the junction, so as to establish their presence, or
- **Design approach B:** Segregation is brought right up to the junction (<=5m) and very tight geometry (and often raised crossings) used to keep turning speeds down and encourage vehicles to cross the cycle lane at close to 90 degrees.

Examples of returning cyclists to the carriageway can be found in Dutch, German and Danish guidance, again with examples of both very short (or no) 'set-back', and longer distances of around 20 to 30m. As there are many important contextual differences, including different rules on priority for cyclists using adjacent cycle tracks, it is hard to draw direct comparisons with the UK. Both Danish and Dutch guidance mentions different approaches being taken at different junctions.

Design approach A appears to be preferred where traffic speeds and flows are higher. Design approach B is particularly widespread in countries such as the Netherlands where cycling is commonplace and cyclists using cycle tracks adjacent to the carriageway are given explicit legal priority at side roads, as well as implied protection from rules on liability for motorists.

For both approaches (A and B), coloured cycle lanes and other markings are usually recommended to highlight the presence of cyclists to drivers where a cycle lane is marked across a side road. Additionally, speed reduction measures, in particular raised crossings, to reduce vehicle speed when turning and to position turning vehicles at right angles to the cycle lane (so as to improve visibility) are also recommended in the literature.

[4] Annexes available from: www.trl.co.uk/cyclinginnovationtrials

2 Trial aims and objectives

The overall aim of the programme of trials was to investigate how different segregation set-back distances affects the behaviour of drivers and cyclists under the trial conditions, and so gain a better understanding of the implications for implementing different set-back distances on road. The overall objectives were:

- What set-back distance minimises the risk of conflict between all road users?
- What set-back distance is the most appealing and preferred by the different road users?

Individual methodologies with specific research questions were developed for each trial, but in summary the trials sought to gain information on how the different set-back distances affected the following:

- Vehicle speed - did the drivers have to slow down more with shorter segregation set-backs?
- Position in lane on approach and when turning - did drivers encroach into the cycle lane? How much space did they give cyclists?
- Stopping position - did drivers encroach on the cycle lane when waiting to turn across it?

In addition the trials considered qualitative questions, in particular:

- How did the different layouts affect how safe participants felt?
- How did they affect their understanding of the layout, and who had priority?

For full details of research questions for individual trials please see the appropriate Annex[5].

[5] Annexes available from: www.trl.co.uk/cyclinginnovationtrials

3 Design layouts tested in trial

Three trials were carried out on the Small Roads System (SRS) at TRL's test track, and one using TRL's Digi-Car simulator[6]. The junction layouts used for the test track and simulator are described below.

3.1 Layout for track trials

The design layout for the track trials is shown in Figure 2: . The location plan showing the site position on the SRS is shown in the technical Annexes[7].

The layout comprised a 2.0m wide cycle track at carriageway level, continued as a coloured cycle lane across side road. A 0.5m wide kerbed margin was used to separate the cycle track from the main carriageway, with a gap at the junction to allow vehicles to turn into or out of the side road. The distance at which the segregation ended before the junction was varied by using moveable kerbs, so that the segregation could be set-back at a range of distances (at 5m intervals) between 5m and 30m from the junction. This was measured from a projection of the side-road kerb line to the end of the segregated cycle track, see Figure 1

Figure 1: Setback distance

[6] More details available from: www.trl.co.uk/facilities/driving_simulation/

[7] Annexes available from: www.trl.co.uk/cyclinginnovationtrials

Where no segregation was present a chevron marking between double solid white lines was visible.

The surface of the cycle lane was coloured green throughout, i.e. both within the kerb segregated track and across the mouth of the side road, additionally using triangular give-way markings to highlight the cycle lane for turning vehicles. These are illustrated in the photograph in Figure 2. These markings are not an approved road marking in the UK, however somewhat similar versions are used in the Netherlands as a 'give way' marking.

The fourth arm of the junction was coned off for the majority of time during the trials as it was not required for the scenarios under investigation.

For the second trial (trial code 'M2') a dropped kerb was provided 4.7 m before the side-road itself. This was for participant cyclists to leave the road just before the conflict point. To ensure that safety could be managed in this trial, which could have placed participant cyclists in conflict with participant drivers, it was designed so that no cyclist crossed the junction.

Video cameras were set up at 10 locations, covering the full area shown in Figure 2: . An example of the view from a video camera is shown in Figure 3. All three approaches to the junction were monitored with the main focus being close to the junction. This permitted measurements to be taken of vehicle position on the approach and when turning, and to enable the average speed of the participants to be measured over the final 60m length ending at the junction: depending on whether they were turning into, or out of, the side road respectively.

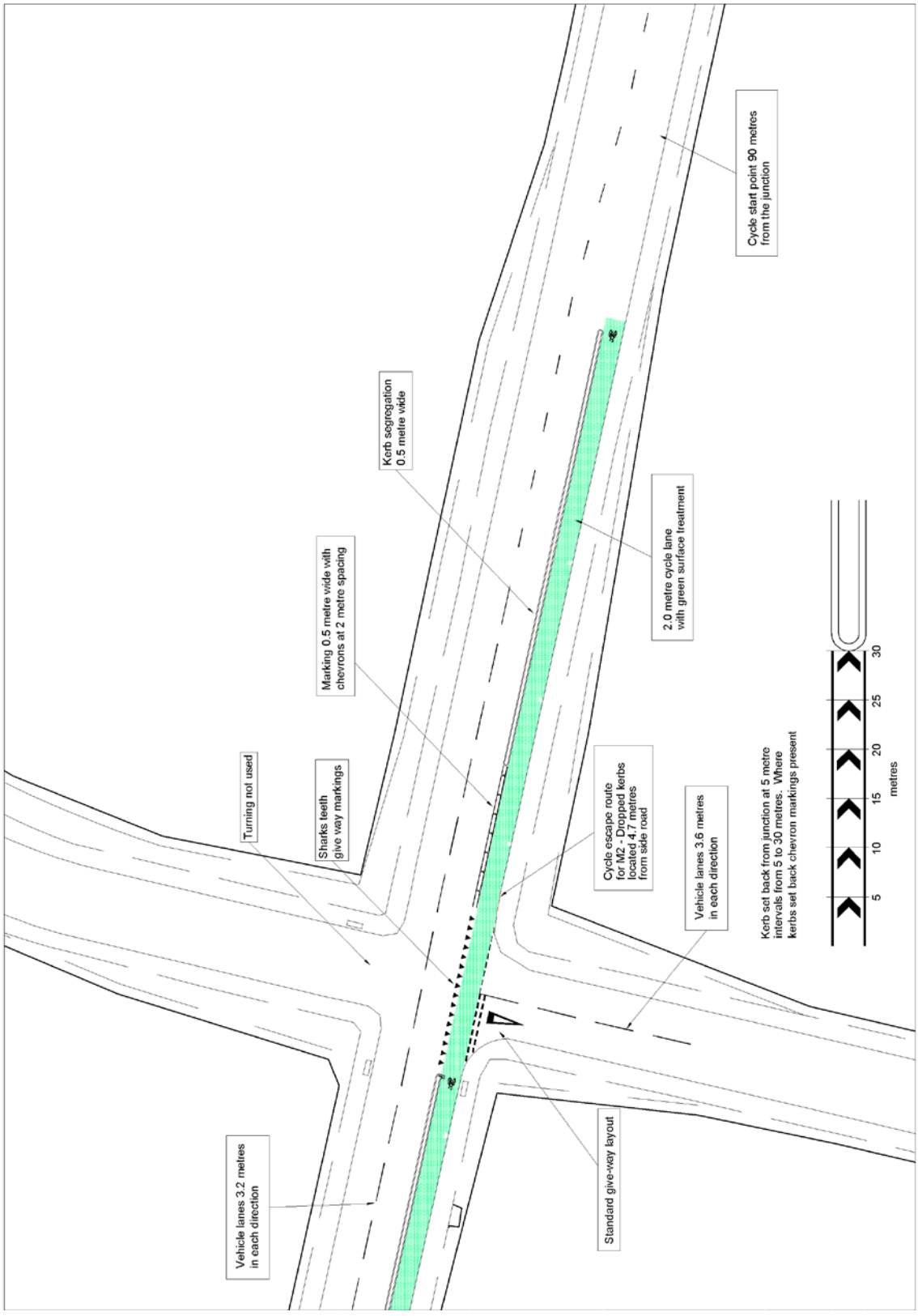


Figure 2: Design layout for track trials (M1, M2, and M4)

Figure 2: Cycle lane marked across the junction using triangular markings

Figure 3: Screenshot from a video camera looking back towards cyclists' starting point

3.2 Design layout for the simulator trial

The trial was undertaken using TRL's driving simulator, DigiCar. Participants were presented with a naturalistic driving task in a generic urban (London-like) environment with appropriate buildings, pedestrians, cyclists and vehicles (e.g. London buses, black cabs). A segregated cycle lane (with a 0.5m wide kerbed margin) was created within this environment for the purposes of this trial, with segregation set back from the junction at 5m and 20m. It is important to note that the simulated junction had a diferent geometry to the test track- see Section 3.3 for a comparison of their dimensions. This was because it was was based upon an already existing simulated street layout. Figure 4 shows the simulated layout created for this trial.

The DigiCar vehicle is a standard car and the controls are operated as in a real vehicle. The vehicle is mounted on four electric actuators connected to the axles behind each wheel to provide motion with three degrees of freedom; heave, pitch, and roll. The simulator provides 210º forward field of view using three flat screens. A rear screen gives a 60º rearward field of view with a display that is adjusted to appear correct for each of the driving mirrors. Simulator data relating to participants operation of the vehicle and the position of the vehicle relative to the conflicting cyclist and the segregated cycle lane were recorded and used to compare driving behaviour across experimentalconditions.

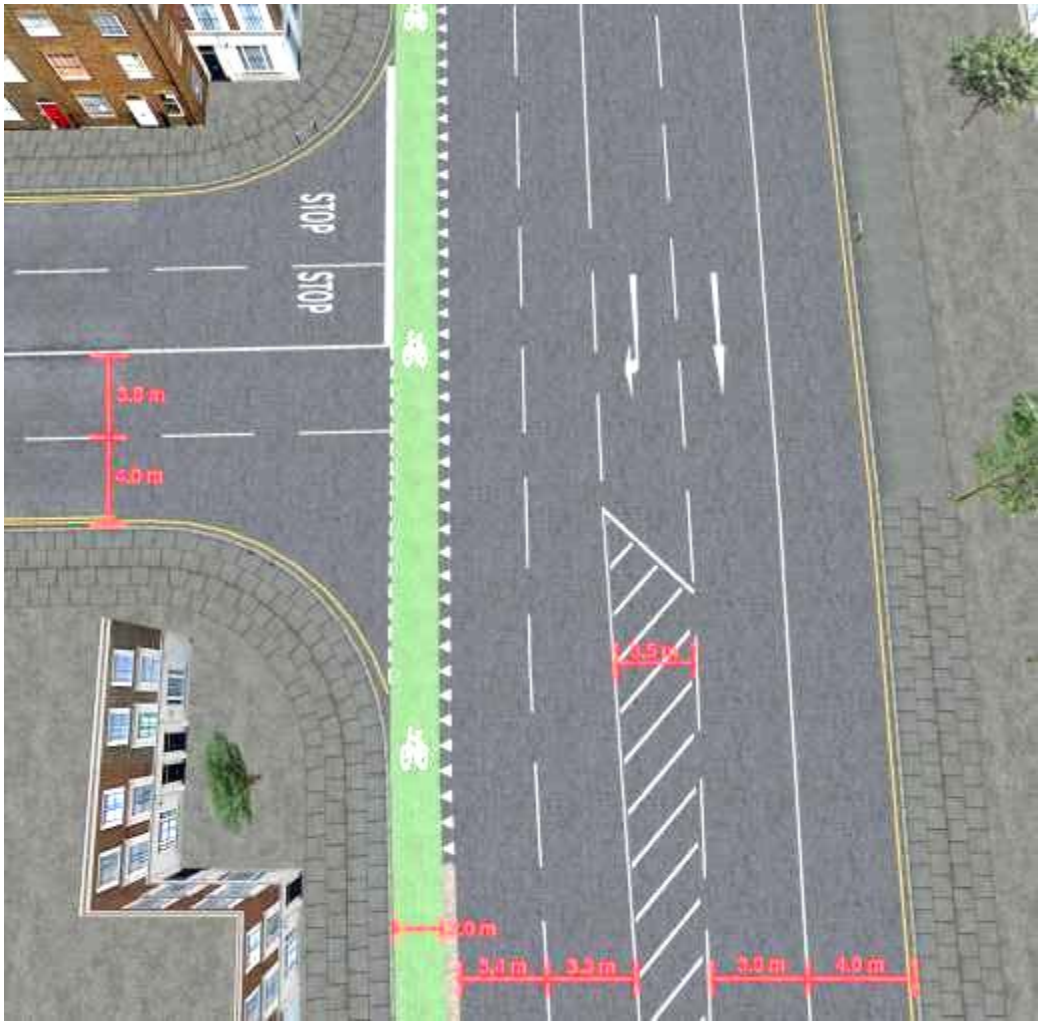


Figure 4: Screenshot of simulated layout showing lane markings and widths for M13 trial

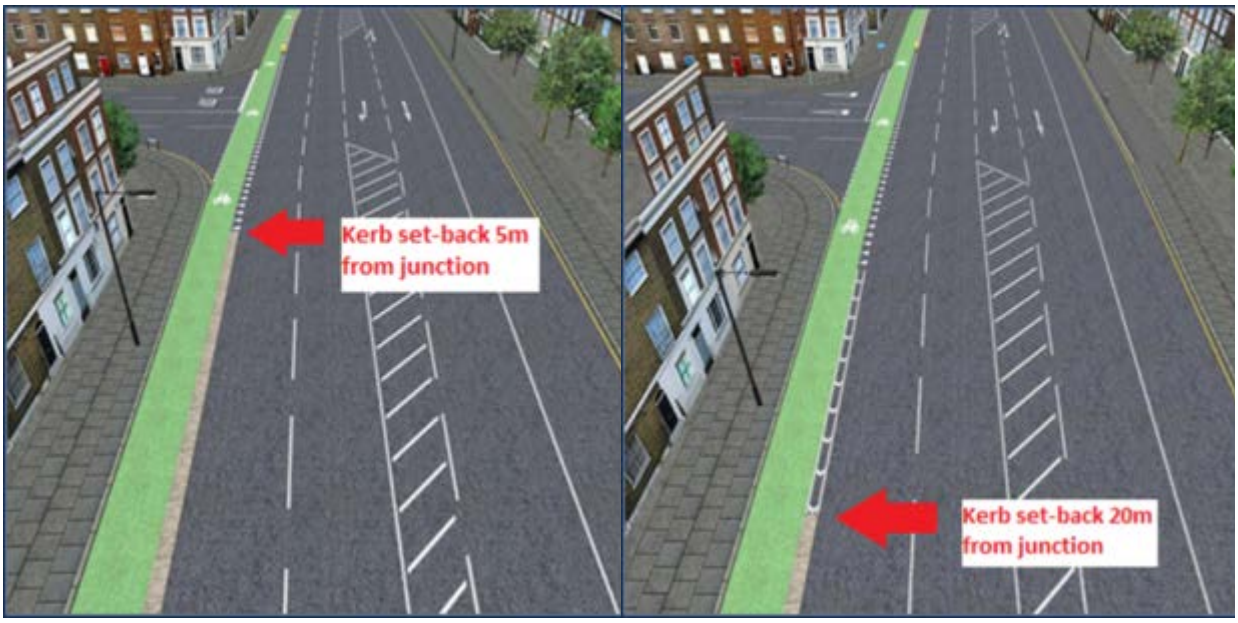


Figure 5: Screenshots showing the two kerb set-back variations of 5m and 20m from the entrance to the side road

Figure 6: Driver's point of view of the same conflicting cyclist crossing the side (conflict situation). The driver will turn left into this side road

3.3 Track and simulator layouts compared

As explained previously, is evident from a comparison of the drawings of the two layouts there are some significant differences between them. It is important to be aware of these differences when comparing the results of the trials, so a brief summary is given in the table below.

Table 1: Comparison between test track and simulator road layouts

Design feature	Track layout on Small Roads System	DigiCar Simulator layout
Number of lanes	Single vehicle lane in each direction on both main and side road	Two vehicle lanes in each direction on both main road and side road; hence there were separate lanes for turning left and turning right out of side road.
Lane widths	Main road 3.2m Side road 3.6m	Main road 3.4m (inside lane) Side road 4m (inside lane)
Separation between opposing traffic flows	Dashed white line only	Hatched marking in centre of road
Segregation set-back distances	5m to 30m in 5m intervals	5m and 20m

In summary the simulator layout was much wider, with more lanes available and greater separation between opposing flows of traffic. Drivers therefore have much more space available when turning, which is likely to reduce the impact different kerb set-back lengths have on turning paths at the junction.

4 Summary of trials conducted

The three track trials and one simulator trial involved creating different trial scenarios. The track trials were developed sequentially with progressively greater complexity. This was necessary for safety reasons, because of the requirement for TRL to be able to manage potentially conflicting situations on its premises, in compliance with its health and safety responsibilities as an employer. It also enabled progressively more complicated methodologies to be designed using experience gained from the previous one.

4.1 Track trials M1, M2 and M4

The three track trials are summarised below, a more detailed description of each trial is available in the technical annexes[8].

- The first trial, code 'M1', involved 16 participant goods vehicle drivers only, with no cyclists. Drivers drove along the main road, alongside the segregated cycle lane, and then turned left into the side road. Stationary bicycles were positioned at fixed intervals along the cycle lane to provide a visible 'cyclist' presence to help assess drivers' perceptions of safety at the junction. With the small sample size this trial was largely qualitative.
- The second trial, 'M2', involved both car drivers and cyclists as participants. Drivers turned left into the side road while participant cyclists rode in the cycle lane towards the side road. So that safety could be managed during the trial, which could otherwise place two groups of participants in conflict, the cyclists exited the carriageway using a dropped kerb; this was at 4.7m from the side road.
- The third trial, 'M4', involved participant car drivers turning left and right, into and out of the side road. TRL staff cyclists rode along the cycle lane and continued across the side road (the use of staff as actors in this trial made it easier to control the scenarios created on track and to manage safety).

Further details of numbers of participants and manoeuvres considered are provided in **Table 2**.

4.2 Driving Simulator Trial M13

In the driving simulator a very similar layout was used, with the same markings to take the cycle lane across the junction. However, the simulated road was much wider, with two vehicle lanes in each direction, wider lanes (3.4 m compared with 3.2) and a wider side road. The road widened from 11.4 m to 12.1 m on approach to the junction. In the simulator participants were all car drivers instructed to follow a course that would require them to turn left into the side road that had the cycle lane crossing, there were also simulated cars and cycles. A total of 12 scenarios were set up with two set-back distances (5m and 20m); the presence or absence of a potential conflict with a cyclists at the side road; and three different 'densities' of cyclists. The choice of only two set-back distances was made as a result of preliminary findings from the on street trials, which indicated that the intermediate distances would not be recommended for implementation- see discussion in results section.

[8] Annexes available from: www.trl.co.uk/cyclinginnovationtrials

Table 2: Summary of trials carried out

Trial code	Type	Participants	Trial situations created	Set-back distances
M1	Track	16 goods vehicle drivers (4 types of vehicle)	Driver turns left into side road. Stationary cycles parked in cycle lane at defined distances from junction.	5 to 30 m in 5 m steps
M2	Track	66 car drivers and 66 cyclists	Participant driver turns left into side road Participant cyclist rides as if they were continuing straight ahead. However, they left the carriageway just before the junction and went onto the footway using a dropped kerb, so an implied and not a direct conflict occurred with the car drivers.	As above
M4	Track	90 car drivers	Participant drivers turn left and right into side-road, and left and right from side-road into main road. TRL staff cyclists go straight ahead from segregated lane, crossing mouth of side road.	As above
M13	Simulator	30 car drivers	Participant drivers follow a pre-defined course, which includes a left turn into a side road following a segregated cycle lane. Twelve scenarios from combinations of: • 2 set-back distances • 3 'densities' of cyclists on road • 'with' and 'without' conflicting cyclist at junction	Segregation set-back of 5 and 20m.

4.3 Methodology limitations

The situations presented to the participants in each of the track trials M1, M2 and M4 were necessarily lacking some aspects of realism. However, participants' relative judgements of the presented situations were based upon consistent circumstances. Thus their assessments provided a clear insight into driver and cyclist preferences. There were some aspects common to all the track trials, participants were:

- Aware they were being studied.
- Less likely to be engaged in any other distracting tasks (e.g. using mobile phone, adjusting radio etc.).
- Not under time pressures.
- Likely to drive more carefully than they would on the road.
- Not having to interact with other vehicles.

Nevertheless, such experiments provide good insights into relative behaviour and can therefore be used to investigate the comparative (although not absolute) safety of altering designs and measures

It should also be noted that these trials did not consider features such as bus stops, on-street parking, loading/drop-off zones or pedestrian crossings which would often be present in real-life situations and would affect driver behaviour.

In addition to the general limitations described above, the following should be taken into consideration for each trial:

For **trial M1 (Goods vehicles)**, participants were:

- Goods vehicles travelling at relatively low speed: an average of less than 14mph over the 60m before the side road.
- Aware that they were not going to come into conflict with cyclists.
- Provided with clear information about their route.
- Dealing with stationary bicycles, so don't have to make any assessment of relative speed when deciding whether it is safe to turn in front of a cyclist.
- Aware they are not passing actual cyclists which will affect their judgement of acceptable passing distances.

A further limitation of the trial is the small sample size, which is suitable for providing only indicative information on the behaviour and opinions of goods vehicle drivers in general.

For **trial M2 (Cyclists and car drivers)**, participants were:

- Aware cyclists will not actually continue straight on, and therefore a conflict cannot occur in reality.
- Not constrained by opposing flow to limit turning movements into the side road;
- Provided with clear information about their route.

For **trial M4 (Car drivers)**:

- Interactions were between single vehicles and single cyclists, this simplifies the decision making process and making it easier for either party to stop without concern that they might create a conflict with a following vehicle or cyclist.
- There were no following vehicles putting pressure on the drivers to make progress.
- No opposing traffic flow to limit turning movements into the side road.
- Speeds were relatively low at all times; the average speed of each vehicle was between 9 and 15 mph over the length of the run.

For **trial M13 (car drivers)**, whilst the driving simulator does provide a level of realism in terms of the vehicle being driven and the view observable it is none the less evident that the view is computer generated, and there are no inertial forces created such as the sideways force experienced when makings turns.

5 Results

Detailed results for each trial are set out in the technical annexes to this report[9]. A summary of the key findings is given below. In this report short set-back distances are less than 5 metres, and long set-back distances are greater than 20 metres.

Data were provided by the questionnaires and video analysis. Statistical analysis of the questionnaire and video data has made it possible to identify findings that are 'statistically significant' (i.e. any pattern or relationship in the data that has a small probability of occurring by chance). It is commonly accepted that if a finding has occurred with a probability of 5% or less that it occurred by chance, then it is statistically significant.

5.1 M1 Goods Vehicle Drivers

The findings from this trial are based upon the Goods Vehicle drivers' perspective on the effect of different segregation set-back distances, and were judged with stationary cycles. These cycles were located at 10 metre intervals close to the nearside kerb, within the cycle lane.

The following observations were made on the impact of different segregation set-back distances:

- Short set-backs (i.e. ending the kerb segregation close to the junction) reduce the effective turning radius, which makes it harder to make a turn into the side road and therefore drivers responded by reducing their speed and making a sharper turn across the cycle lane.
- When asked about their preferences for set-back distance, more goods vehicle drivers preferred to maximise the extent of segregation from cyclists, rather than having cyclists joining the main traffic early.
- Overall, medium set-backs (15 to 20 metres) appeared to be goods vehicle drivers' preferred compromise as cyclists remain segregated for longer and drivers can still easily make their turn into the side road. The goods vehicle drivers consequently judged this overall as the safest set-back distances from their perspective.

The findings from this trial represent only the goods vehicle drivers' perspective on the effect of different set-back distances, and it is important to note that this perspective is based on their responses to a situation that does not involve real, moving cyclists. However, within these constraints the findings of this trial have some interesting implications.

The preferred set-back distance for 62%of the drivers (who expressed an opinion) was one that maximises segregation from cyclists on the approach to the junction. However drivers still wanted to be able to turn whilst maintaining their normal turning speed and path. As the trial did not include moving cyclists it is not possible to assess whether the drivers' judgement of whether to pass a cyclist or hold back was a safe one. It is possible therefore that the arrangement the drivers preferred is not the safest one, considering

[9] Annexes available from: www.trl.co.uk/cyclinginnovationtrials

that their judgements on whether or not it is safe to pass a cyclist before the junction may not have been accurate.

On the other hand, the drivers' response to the tight geometry created by a very short set-back distance was to reduce speed and take a sharper turn across the cycle lane. Potentially such a change in driver behaviour could have safety benefits for cyclists since it minimises the area in which there is potential for vehicles to encroach into the lane while placing more of the cycle lane in the drivers' direct line of sight as they cross it.

5.2 M2 Car drivers turning into the side-road and cyclists going ahead

The findings from this trial are based on both car driver and cyclist participants. The following observations are limited by the scope of this track trial. In particular the fact the cyclists did not actually proceed across the side road; that vehicle speeds were comparatively low and controlled by a guide car, and that no other traffic was present.

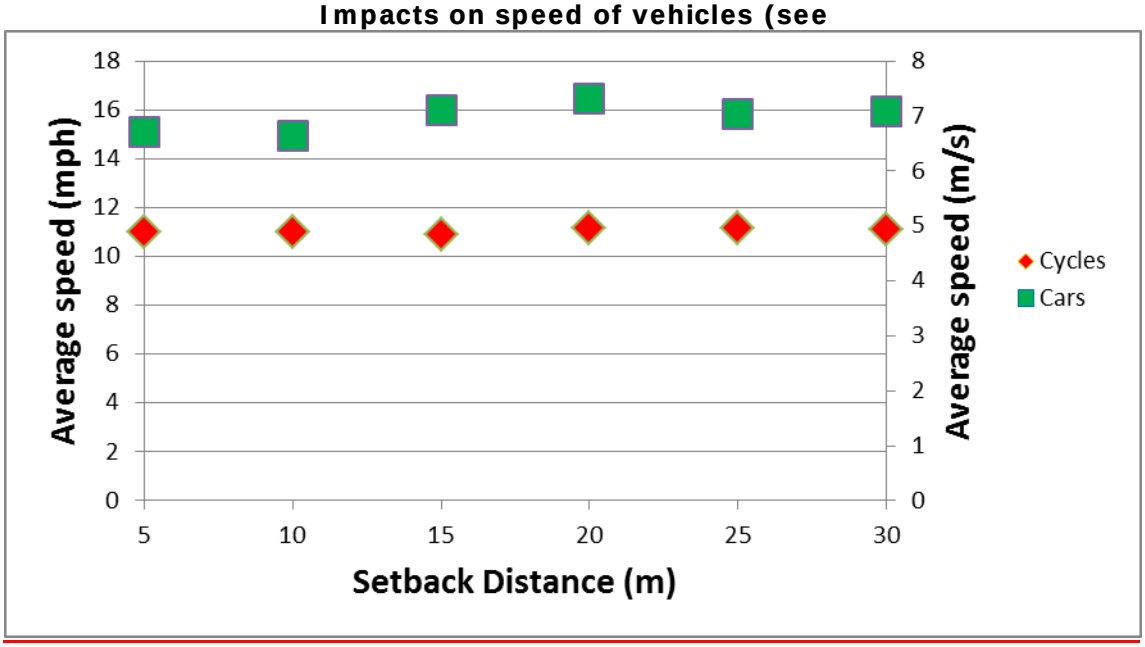
In all cases the car drivers turned left at the side road, whilst the cyclists continued straight on until the drop down kerb, which was 4.7m before the point the turning began.

The trial considered paths, average speed over the length of the run and decisions for the situations created such that when the car driver was 5 metres before the side road, the cyclist was at one of six different distances from the side road: 5, 10, 15, 20, 25 or 30 metres.

The following observations have been made for:

- Impacts on path taken when approaching the junction.
    - The average paths used by the car drivers were consistent for different kerb segregation set-backs between 10 metres and 30 metres. However, their average path varied slightly when there was a 5 metre set-back. The front wheel was 0.4 to 0.8 meters further from the kerb and therefore their path into the side road was more acute.
- Distance of vehicles from cycle lane.
    - The passing distance between the cars and cycles varied between 2 and 3 metres, with an average of 2.5 metres.
- How far vehicles were from the side road when they started moving into the cycle lane.
    - Measurements of the paths taken by vehicles showed that cars entered the segregated cycle lane between 0.6 to 2.3 metres closer to the side road when the cycle lane kerb segregation had a 5 metre set-back, compared with set-back distances greater than 10m.

Impacts on speed of vehicles (see



- Figure 7).
    - Drivers' average speed over the length of the whole run was approximately 1 mph less with a 5 and 10 metre set-back distance than with longer set-backs, and the difference was statistically significant (at the 95% confidence level). It may be that the speed reduction at the turn was much greater than this as it forms only a short distance within the overall length of the run.

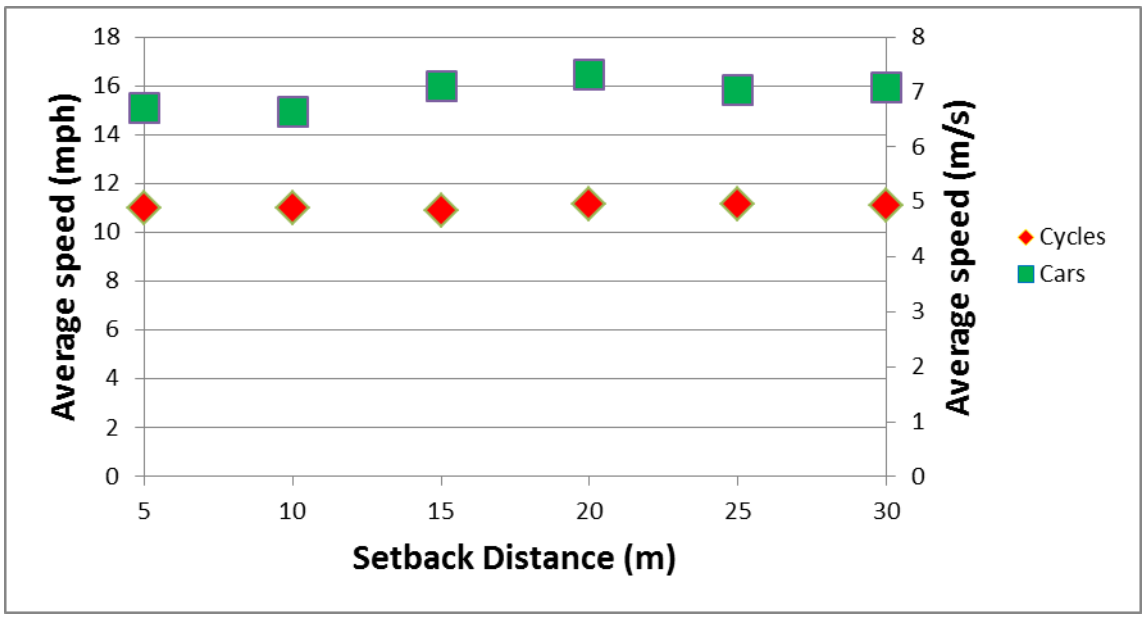


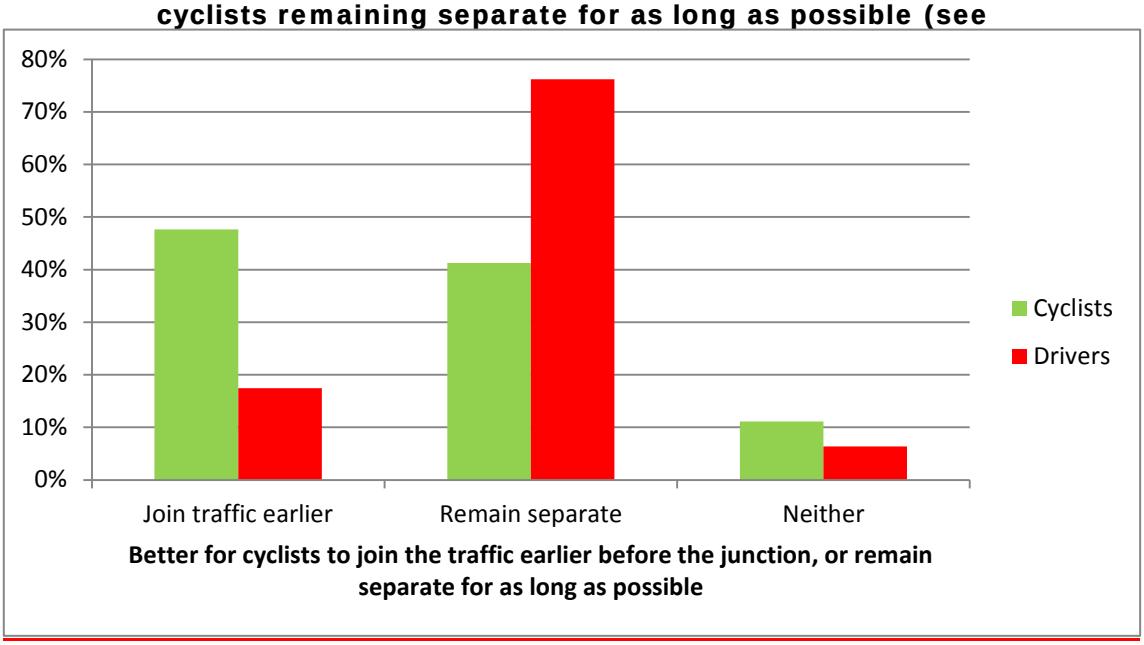
Figure 7: Average Speed over 60m run for each set-back distance

- Impacts on perceived safety and decisions taken.

- Cyclists felt fairly safe on average, but less so than car drivers. There was an indication from the qualitative answers that cyclists' perceived safety increased with shorter set-back distances.
- The highest percentages of decisions to turn in front of the cyclist occurred for long and short set-back distances.

- Impacts on ability of cyclists to achieve their preferred position in the road.
  - Most cyclists stated that the set-back distance had no effect on their ability to judge the speed or position of the motorist and to get into the correct position to continue across the junction. Among those that said there was an effect, slightly more participants noted that it was easier with a longer set back than with other set-back lengths.
  - Cyclists found it harder to get into position to turn right at the end of the cycle lane when the set-back was short.
- Attitudes towards segregation and reintroduction of cyclists to traffic before junctions.

Cyclists were almost equally divided as to whether they preferred a long, or a short set-back when approaching a side road. Most of the drivers favoured cyclists remaining separate for as long as possible (see



  - Figure 8).

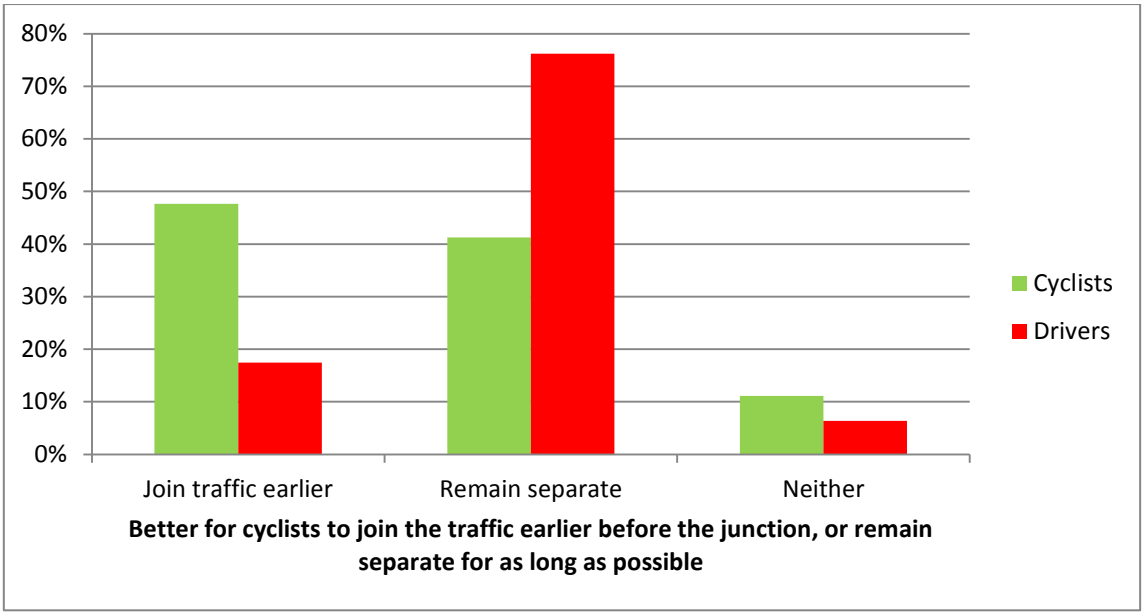


Figure 8: Preferred position for cyclists joining the carriageway after the end of segregation

- Almost half of the cyclists reported no concerns with any set-back distances, and almost half had concerns with the shortest distances to the junction (5m to 10m). Most drivers (over 80%) reported no concerns; of those with concerns, the main concern was with the shortest set-back distance.
- Cyclists tended to find it easier to decide whether it was safe to continue with a long set-back, they were also more likely to then consider that it was safer to continue straight on. However, the proportion preferring any one set-back distance was not significantly greater than the proportion preferring the other ones.
- Concerns expressed by cyclists included concerns that drivers may not be expecting to have to interact with cyclists when the segregation ends, this suggests that cyclists may feel safer if the segregation ends before the junction so they can merge with the traffic before the turn.
- **Both groups of participants express a preference for highlighting the point where segregation ends, such as the use of signs, bollards or markings.**
- Over half (53%) of those cyclists who said they found junction easier to use with one set-back distance, chose the long set-back.

5.3 M4 Car drivers turning in and out of the side-road and cyclists going ahead

The findings of the report are based on observations relating to car drivers. There were four routes travelled by the car drivers, right into the side road, left into the side road, right out of the side road and left out of the side road. In addition some right turn manoeuvres were carried out with a queue of traffic on the lane closest to the side road. The situations with a queue of traffic are dealt with separately from the other right turn manoeuvres and hence there are six different scenarios types in total.

5.3.1 Summary of findings from video and track-side questionnaires

The results for each route were examined individually. The following observations have been made for:

- Path
    - o There was a statistically significant difference between the paths the cars took when the set-back distance was 5 metres, compared to all other set back distances. The set-back distance had little or no effect on the paths taken by cars when the set-back was greater than five meters. The effect the five meter set back had was that drivers approached the cycle lane at a more acute angle, maintained their distance from the cycle lane for longer, and remained out of the cycle lane for longer.
    - o It was found that the passing distance of the car from the cyclist with a 5 metre set-back was significantly greater than with a 10 metre set-back: the difference being approximately one-third of a metre (see Figure 9)

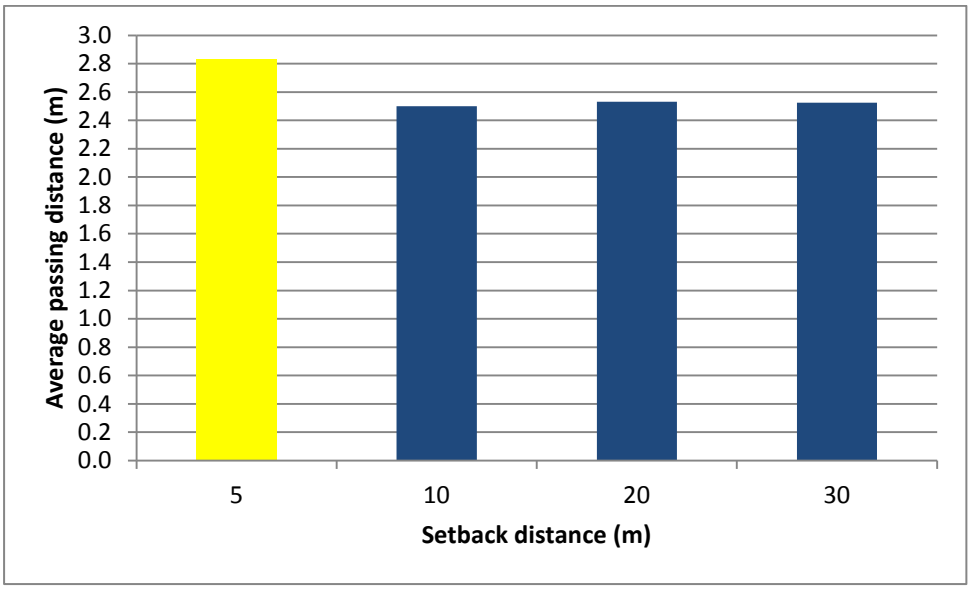


Figure 9: Average passing distance: Turning left

    - o Also, there was a small effect on the car drivers' paths when turning right onto the main road with a 5 metre set-back, with drivers using a more acute angle when exiting.

- The deviation in path when drivers turned left into the side road with a 5 metre segregation setback was statistically significant compared with a 10 metre set-back (see Figure 10).

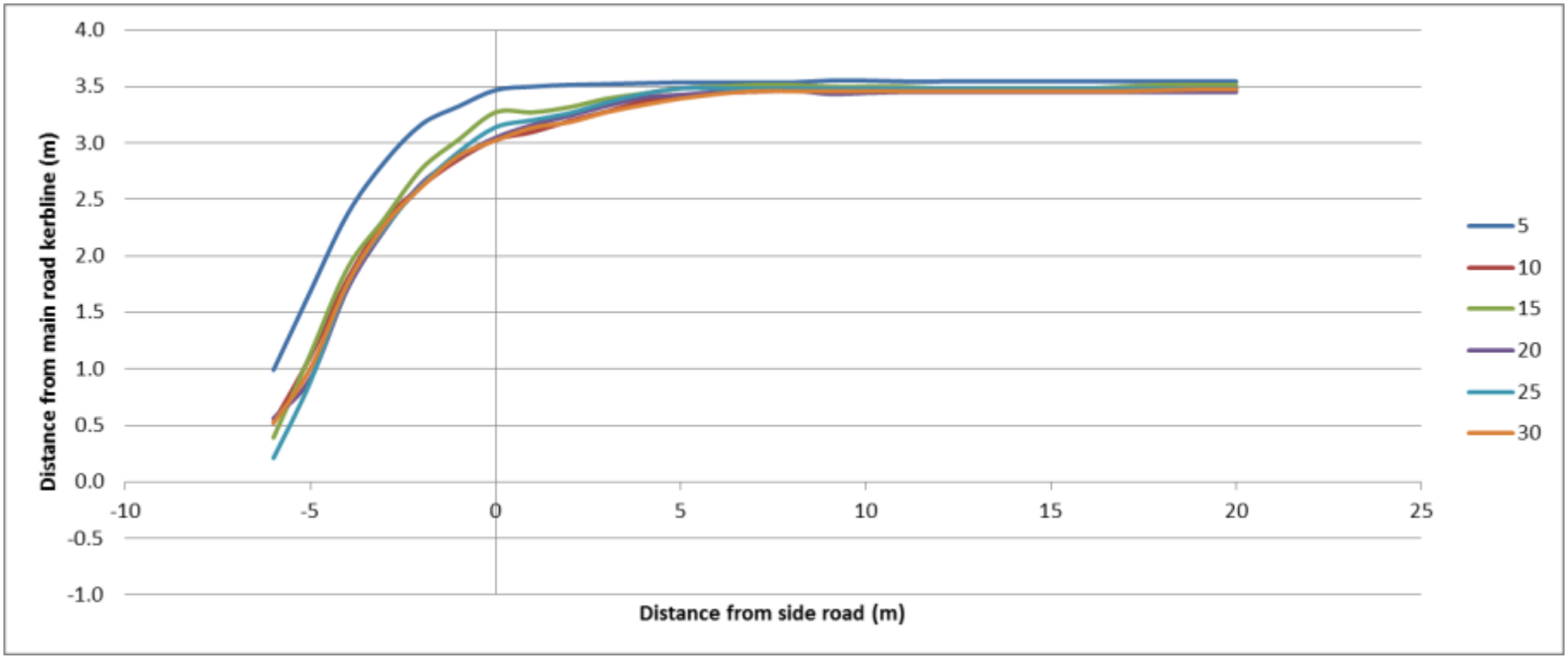


Figure 10: Average car path into side road: Turning left

- Decision making
    - Significantly more drivers (approximately 15%) chose to turn behind the cyclists with a 5 metre setback when turning left into the side road.
    - Set-back distance had no effect on this decision for those turning out of the side road.
- Speed
    - The speed was measured as averages over the last 60m of a run so this will understate any speed reduction taking place at the turning, however statistically significant average speed reductions were observed when comparing 5m (11.6mph) and 10m (12.4mph) set-backs.
- Perceived safety reported by driver at track-side
    - Perceived safety did not vary significantly with set-back distance, except for 5m, which they considered slightly, but statistically significantly, less safe when turning into the side road: a change of 0.7 on the safety scale out of 10. As this was combined with lower speeds and changed path this could be regarded as showing a greater degree of caution for this set-back distance.

5.3.2 Key findings: post-trial questionnaires

The small sample size means the qualitative questionnaire results are not representative of the wider population. Even so, the views that have been expressed highlight issues which are potentially of concern.

- Ease of use.
    - The majority of responses show that participants found the junction to be safe for all the turning movements investigated, and found it easy to see cyclists, judge their position, make a decision about whether to overtake the cyclists, and to be able to make the turn. However, for the minority expressing concerns, the most difficult manoeuvre was found to be turning left into the junction. Other comments refer to difficulty seeing the cyclists to their left, and judging their speed; as well as referring to the perceived risk of hitting the kerb.
- Effects of different segregation set-back distances.
    - When asked about the effects of different segregation set-back distances more than half of the drivers said it made no difference to safety. Indeed 26% did not notice that the set-back distance had varied. While there are some contradictions in the different responses, the overall preference appears to be for set-back distances that maximise segregation from cyclists while minimising effects on turning, i.e. not requiring drivers to slow down significantly or deviate from a turning path.
- Understanding of the purpose of the segregation set-back.
    - **The purpose of the segregation set-back was not well understood - most believing it to be to make it easier for vehicles to turn, only a few referred to it providing space for cyclists and drivers to adjust to each other before the junction. This suggests that there is a lack of**

understanding amongst drivers of how cyclists will behave at the junction.

- Segregated cycle provision.
    - Participants were asked a number of questions about segregated cycle provision more generally and also on their understanding of the junction layout used in the trial. The vast majority were supportive of segregated cycle facilities in principle, with safety being the main reason given. However, many comments refer to benefits to drivers rather than to cyclists, such as not having cyclists in their way in traffic, not having to deal with overtaking cyclists and not having to be as aware of cyclists when they are segregated.

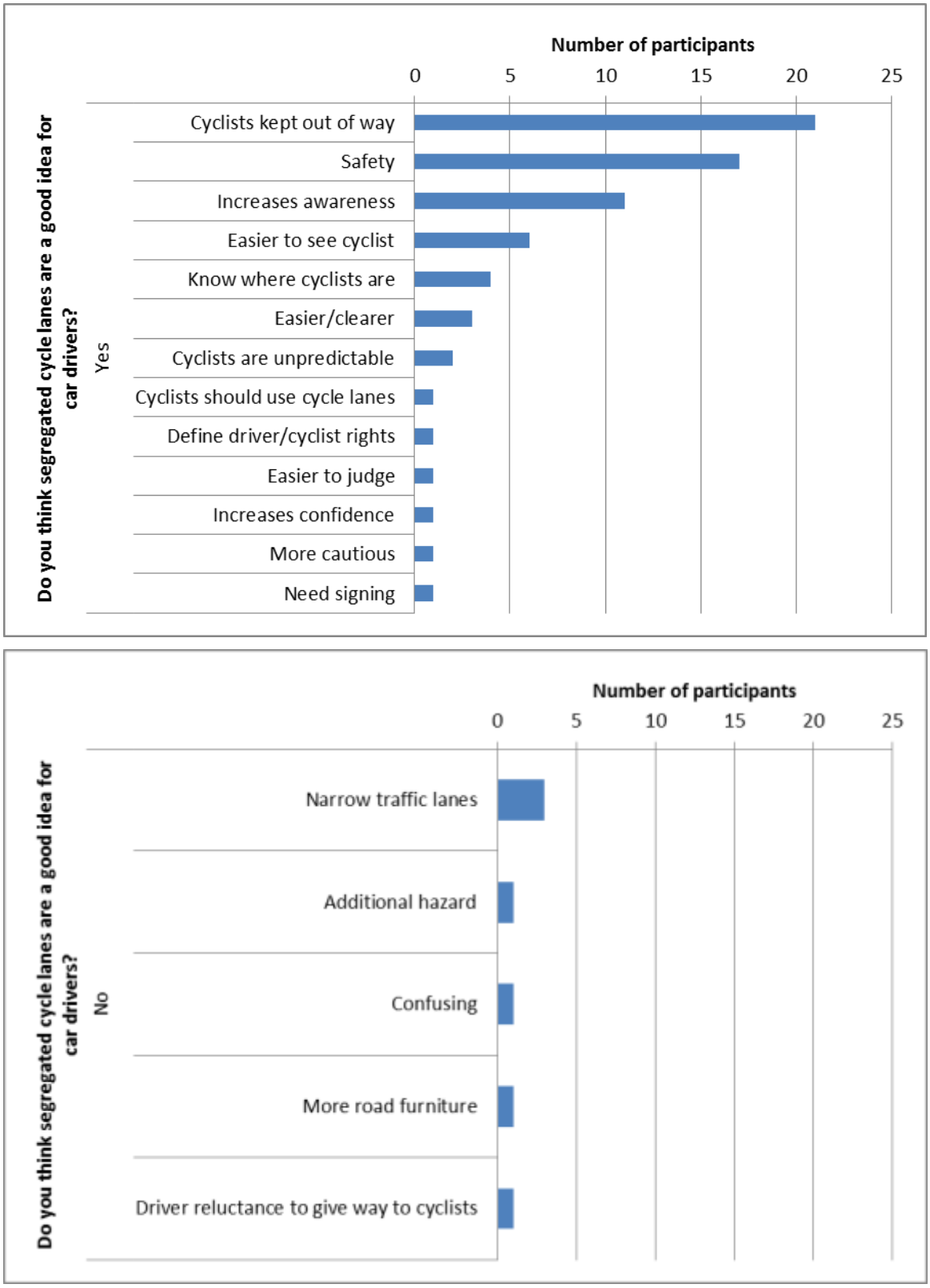


Figure 11: Comments on benefits of segregation reported by participants

- Understanding of Markings.
  - Nearly two thirds of respondents either did not understand the meaning of the mandatory cycle lane markings that followed the segregation, or did not notice

it. Some responses expressed concern that the end of the kerb line was not visible enough and that it should be more clearly indicated in some way, e.g. with a bollard. It is worth noting that more of the drivers who were turning in claimed not to have noticed the markings than those turning out.

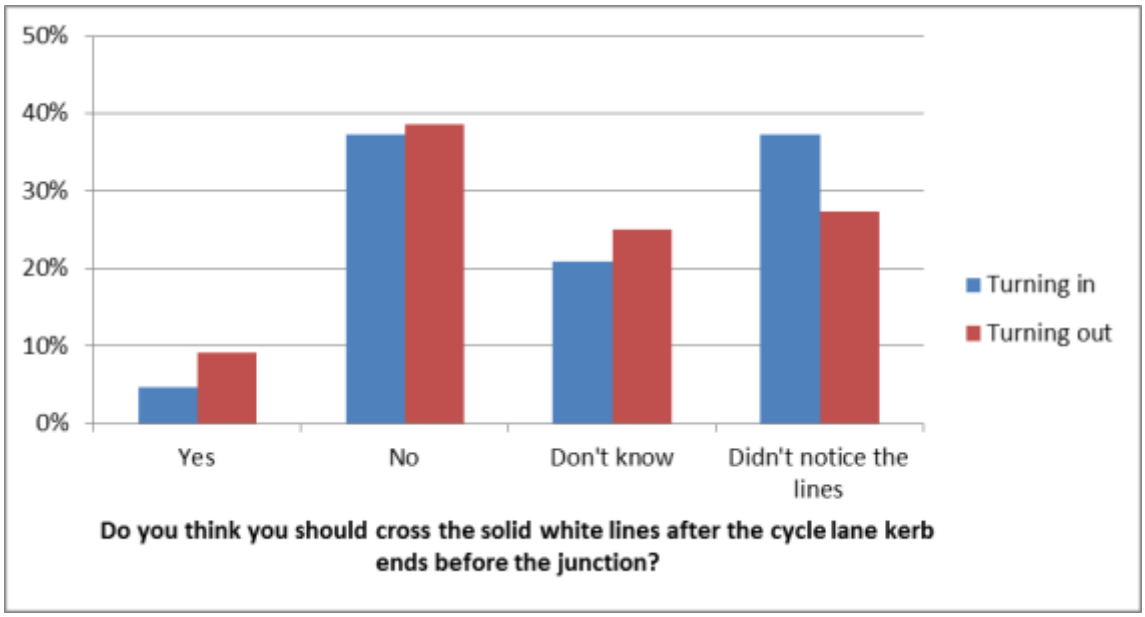


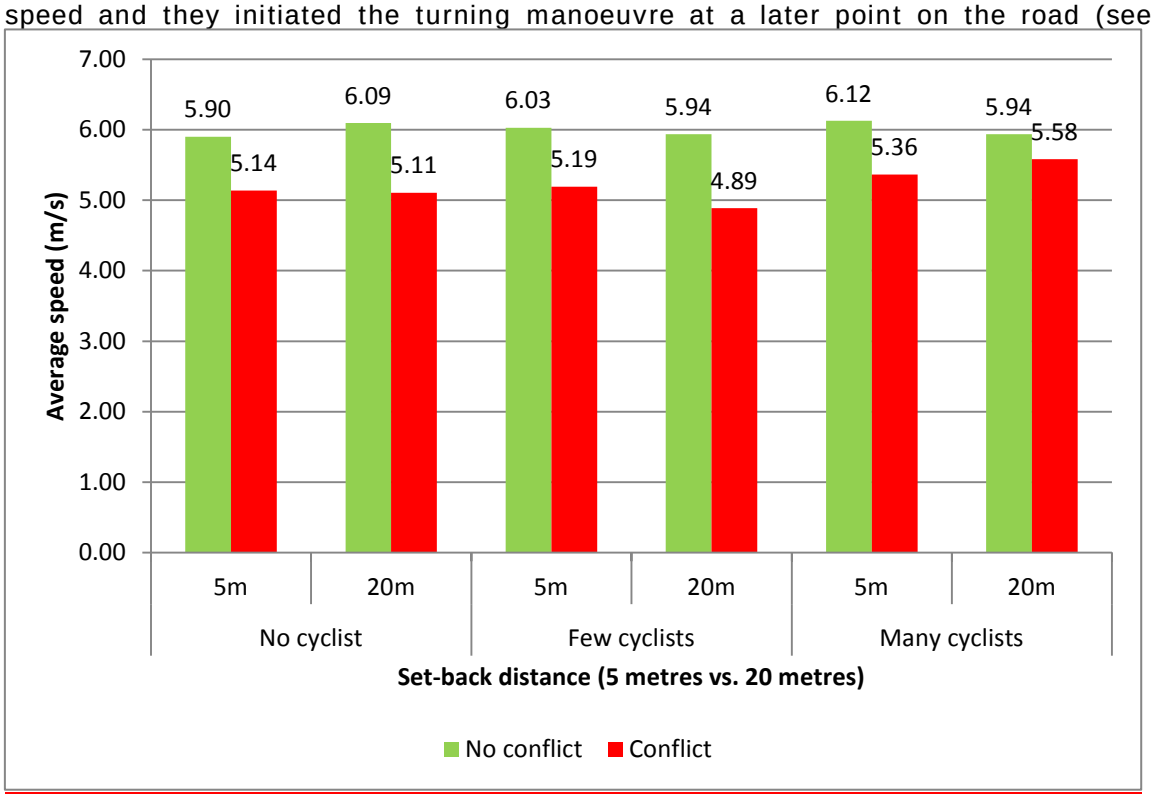
Figure 12: Driver understanding of cycle lane markings approaching the junction

5.4 M13 Driver simulator trial

The following findings are based on car drivers in the driver simulator trial:

- The presence of the segregated cycle lane had a small effect on drivers' lateral lane position. Compared to when there was no segregated cycle lane, drivers' positioned themselves further to the right (0.66 m), leaving a greater distance between their vehicle and the cyclists in the segregated cycle lane.
- No evidence was found that the set-back distances had any effect on drivers' average speed before the junction.
- The results of the study showed that on the approach to the junction and just before the junction, drivers' behaviour was influenced by the presence of a conflicting situation. On average, when there was a conflict, drivers significantly reduced their

speed and they initiated the turning manoeuvre at a later point on the road (see



- Figure 13).

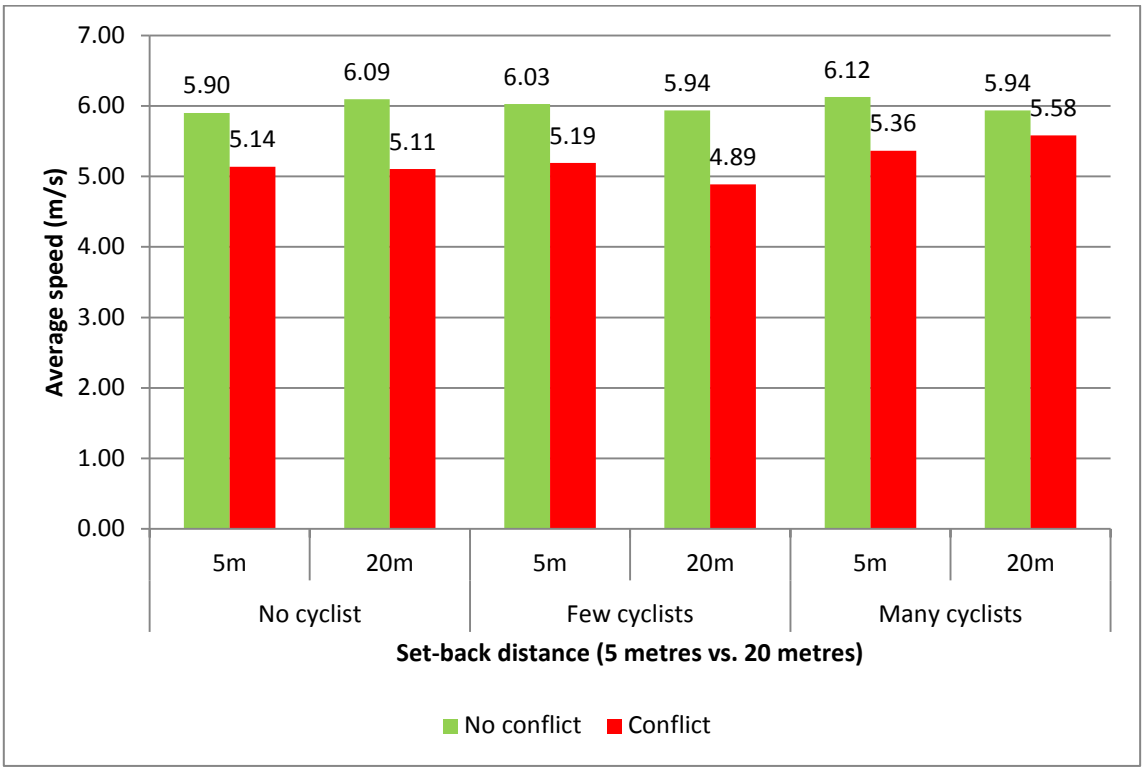


Figure 13: Average speed (m/s) from 5 to 0 metres before the junction

- At the conflict point, there was a significant effect of the density of cyclists in the traffic on drivers' speed (see

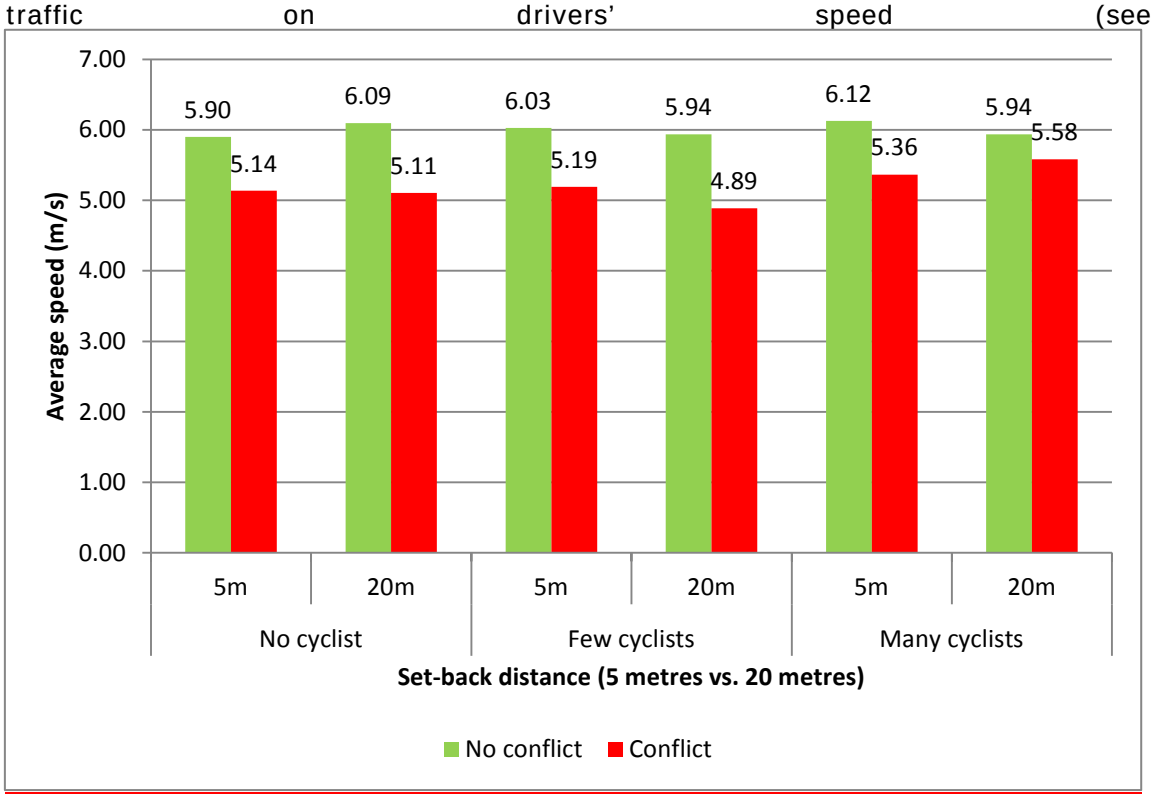


  Figure 13) and drivers' position relative to the cyclist. There was no effect of the set-back distances of the kerb segregation on drivers' position at the point when they initiated the turning manoeuvre.
- A subtle difference in path was observed between the two set-back distances (5 and 20m) in some of the conditions: when there is a 5m set-back distance at the junction, participants selected a larger radius for their turning manoeuvre.

When comparing the results from the simulator trial with those undertaken on the test track it is important to bear in mind the different geometries of the two layouts. The roads in the simulated layout were much wider, with two lanes in each direction, giving drivers far more space in which to turn. It would therefore be expected that the short set-back distance would have less impact on drivers' turning path with the simulated layout as they would be able to use the greater available carriageway width to make the turning. The results show that simply having a short set-back distance of 5m is not sufficient to reduce turning speeds and consideration must also be given to the wider junction geometry.

5.5 Summary

The findings from each study have been summarised in Table 3, Table 4 and Table 5.

Table 3: Summary of trial findings for cyclists

Set-back distance	Speed	Position	Ability to turn?	Key qualitative findings
Short <5m	unaffected	Some felt constrained	Much harder for cyclists to perform a right turn out of the cycle lane	Some cyclists wished to move out slightly earlier when going straight past a side road Regular road cyclists felt that short setbacks made it hardest to decide if it was safe to continue
Medium 5 to 20m	unaffected	Unaffected	Cyclists found it easier to get in position to turn right	Cyclists felt that the medium setback distance was the least safe
Long >20m	unaffected	Unaffected	Cyclists found it easest to get into position to turn right	Cyclists found the long setbacks easier for judging the speed and position of a motorist Cyclists found it easier to use the junction with long setbacks

Table 4: Summary of trial findings for car drivers

Set-back distance	Speed	Position	Key qualitative findings
Short <5m	Approximately 1mph lower on test track layout	Tightest path Least encroachment into cycle lane when turning	Drivers felt they would be nervous using short setbacks at higher speeds Drivers felt it was slightly easier to see cyclists, and to judge their positions Drivers felt that cyclists should remain separate as long as possible
Medium 5 to 20m	Unaffected		Overall drivers felt a medium setback made the junction easiest to use (56% of people with an opinion) and safest for making the turn (44% of people with an opinion) Drivers felt that it increased their awareness of cyclists
Long >20m	Unaffected		Fewer drivers (less than a third) thought that a larger setback was appropriate

Table 5: Summary of trial findings for drivers of goods vehicles

Set-back distance	Speed	Position	Key qualitative findings
Short <5m	Very slightly lower when turning	Tightest path Least encroachment into cycle lane when turning	Disliked by goods vehicle drivers for turning left, but found to be easiest to see the cyclist
Medium 5 to 20m	Unaffected	Unaffected	Easiest to get into the correct position to make the turn, but relates to 15m or greater
Long >20m	Unaffected	Unaffected	Overall easiest to use the junction and easiest to make the turn into the side road

6 Discussion

The video observations for the track trials (M1, M2 and M4) all consistently showed that segregation set-back distance has little impact on car drivers' speed (averaged over the ~60m run) and turning path, with the exception of the 5m set-back. The results from the simulator trial (M13) showed that, with wider (two-lane) roads, even with the segregation only 5m from the junction there is no effect on speed and position. When the segregation kerb is sufficiently close to the junction it has the effect of tightening the turning radius, so that drivers turning left, into the side-road, slow down and take a position further away from the kerb. Although the speed reduction observed in the on-track trails (M1, M2 and M4) is small, it was measured as an average over the last 60m of the drivers' run, so will understate the reduction at the turn.

The simulator trial results also showed that overall there was a significant impact of the presence of a conflicting cyclist on driver speed. That is, when there was a conflicting cyclist present, drivers chose a slower speed. Additionally, when there was no conflicting cyclist, drivers choose a lower speed on average when closer to the junction compared with further away, consistent with the possibility that they were slowing down in preparation to turn left. Another key finding from the simulator was that when a conflicting cyclist was present, average speeds were higher when the driver is closer to the junction (opposite to what was found when there was no conflicting cyclist). This is because, on the approach to the junction, the drivers slowed down to wait for the conflicting cyclist to pass in front on them. Once the cyclist passed in front of the driver the driver increased their speed to make the turn into the side road behind the cyclist.

A further observation from the track trials is that, with the 5m set-back, left-turning drivers left more room between their vehicle and the cycle when passing, and are crossing the cycle lane closer to the perpendicular, which would result in more of the cycle lane appearing in the drivers' direct line of sight.

Video observations showed limited effects of different set-back distance on other turning movements, other than having also to take a more perpendicular angle across the cycle path for drivers turning right out of the side-road. Although there might have been

expected to be a potential problem with drivers leaving the side road encroaching into the cycle lane across the junction mouth, effectively using its outside edge as the give way line, this was not observed in the trial (their use is also covered in other reports in the TfL cycle facilities trials programme[10]).

When interpreting the qualitative findings of the driver-only participants (as in M4) it is important to remember only a minority of these stated that they also cycled regularly, so their perceptions of safety and preferences for junction design are very much from a car drivers' perspective. Thus, 'safety' is often interpreted in terms of wishing to avoid kerbs close to the junction, and being able to turn easily, i.e. without having to slow suddenly or move out to the right. There is a large majority in favour of segregating cyclists from other traffic as much as possible; this was motivated by two things. Firstly, some responses indicate that some drivers lack confidence when faced with having to pass a cyclist in traffic and so would prefer not to have to deal with this situation. Notably, a number of comments refer to the benefit of not having to be as aware of cyclists when they are segregated. Secondly some participants indicated that they perceived more segregation to be safer for cyclists

Overall, turning into the side road was perceived to be more difficult than turning out, with turning left into the side road reporting greatest number of concerns. Difficulties mentioned include seeing cyclists, judging speed and position etc. with references to blind spots and uncertainty about what a cyclist is doing. This is consistent with the observation that turning speed was reduced.

In terms of understanding the effect that the set-back distance has on drivers' and cyclists' behaviour it is helpful to understand how the set-back distance changes two distinct conflicts that occur when a cyclist exists a segregated cycle lane and then crosses a side-road junction. These are:

- The 'merging conflict', which is where the cyclist and vehicle each decide how they will share the road space at the end of the separation.
- The 'turning conflict', which is where the vehicle driver must decide whether to turn before or after a cyclist passes a junction.

[10] Reports available from: www.trl.co.uk/cyclinginnovationtrials

When the segregation ends 20 to 30m from the turning (Figure 14) there is a clear separation of these two conflicts providing more time for decision making and for cyclists and drivers to adapt to each other's behaviour.

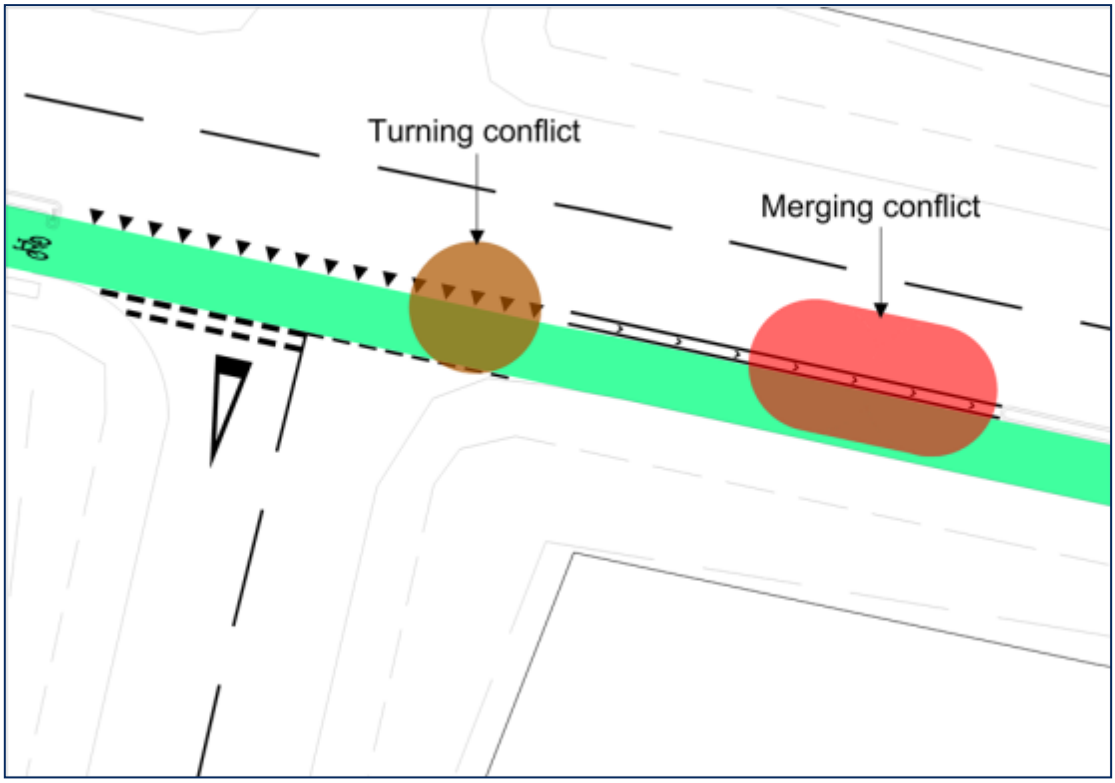


Figure 14 Position of turning and merging conflict for a 30m set-back

When the set-back distance is in the middle range, e.g. around 15m (Figure 15) the merging conflict and the turning conflict are in close succession leaving the vehicle driver little thinking time to make a good decision about whether to turn before or after the cyclist.

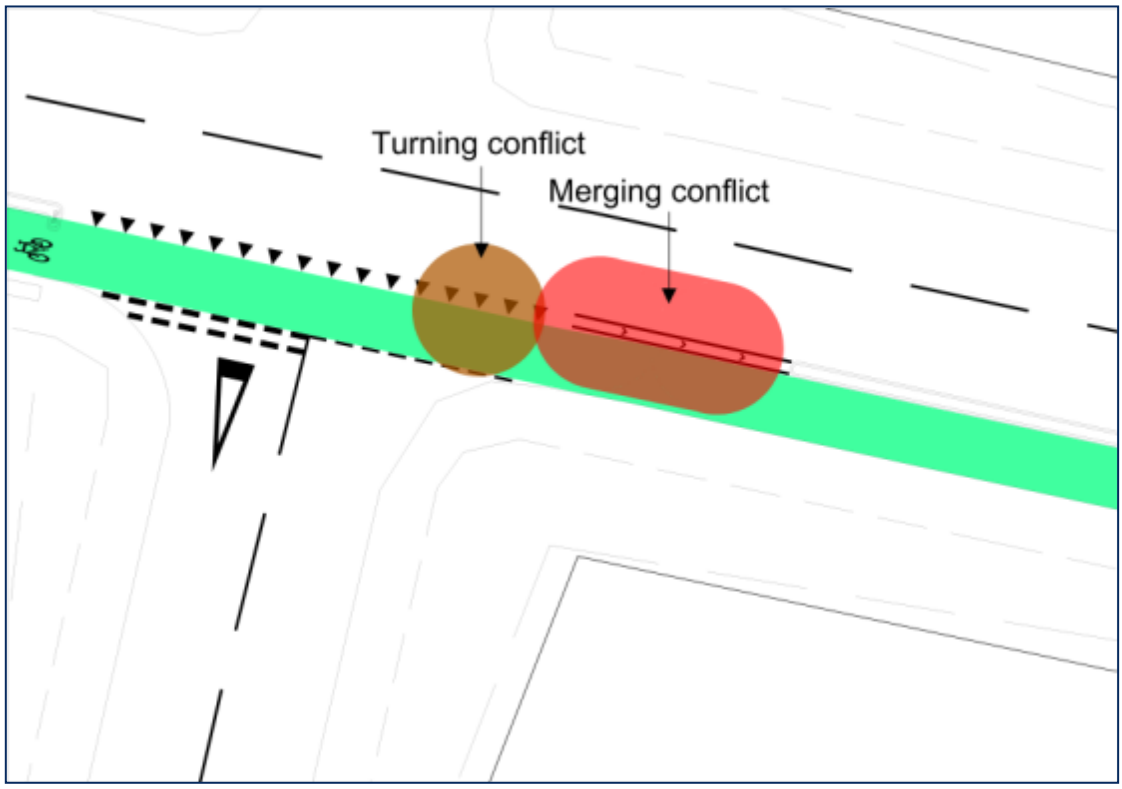


Figure 15 Position of turning and merging conflict for a 15m set back

When the set-back distance is 5m the merging conflict and the turning conflict are combined into a single manoeuvre, requiring only one decision for the driver: whether or not to turn. Vehicle speeds are also likely to be slower due to the sharper angle required to turn into the junction, giving the driver more time to make this decision, and the approach angle closer to the perpendicular, placing approaching cyclists more directly in the driver's line of vision.

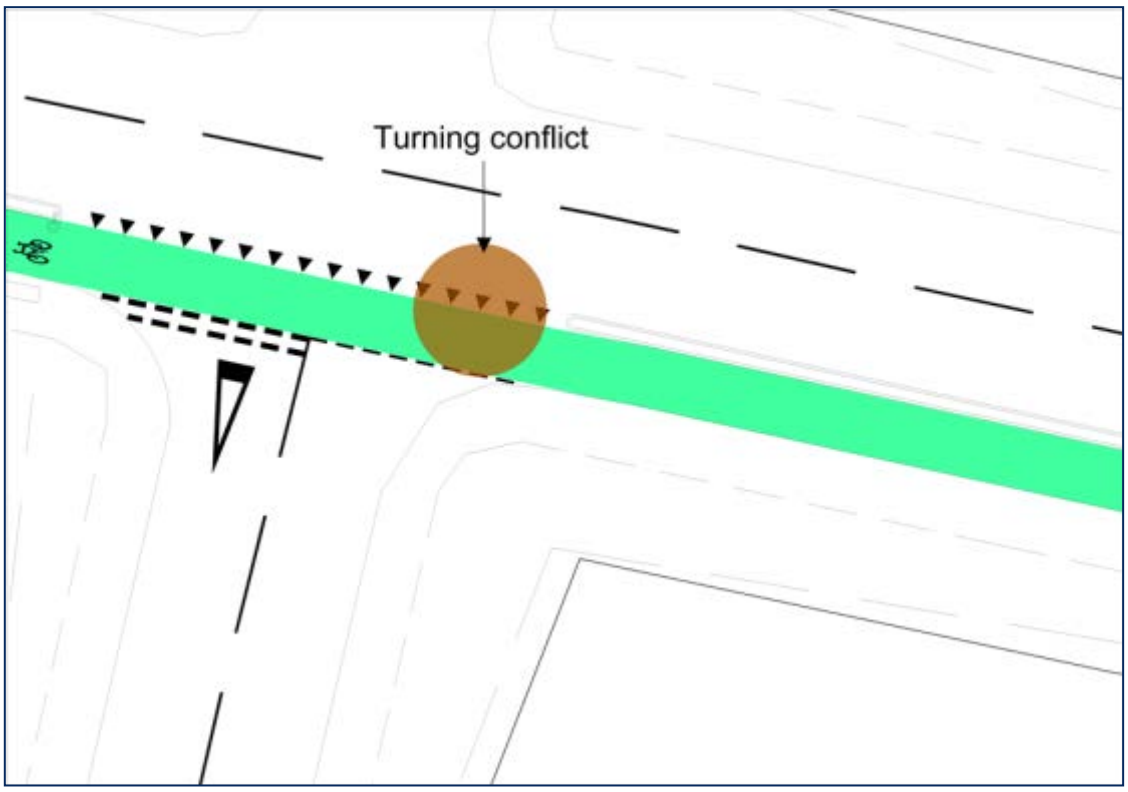


Figure 16 Position of turning conflict for a 5m set back

Where drivers expressed a view as to the purpose of the segregation set-back these principally concerned benefits to drivers, such as being able to turn easily, rather than for the actual intended purpose, which is to permit cyclists to be re-introduced to the traffic flow in advance of the junction to reduce conflict. This suggests that there is a lack of understanding amongst drivers of how cyclists will behave at the junction.

There was a degree of contradiction observed in drivers' preferences for set-back distances depending on what they were being asked about: when considering ease of turn with different kerb lengths there was a greater support for long and medium distances (with the largest number expressing a preference preferring the medium distances); whereas when they were asked how far before a junction cyclists should be re-introduced into the traffic the majority supported the shortest distance. These contradictory answers by the same participants suggests they prefer to maximise segregation while avoiding geometries that affect their path, which also suggest that they are not considering how cyclists will behave at the point of conflict.

Furthermore, some of responses to open questions indicate behaviours and attitudes which, even if only present in a small minority of the population, indicate potential risks that need to be considered, in particular:

- A fairly low level of understanding of the mandatory cycle lane, leading to likelihood that turning vehicles would encroach in it.

- Comments suggesting that some drivers would assume they had priority over cyclists in the cycle lane when turning left.
- Comments suggesting that drivers will give less attention to cyclists in the segregated section of the lane.

Consequently, if drivers' preferences, as expressed in this questionnaire, were used as the basis for determining optimum set-back distance, the chosen value would be one that maximised segregation while not affecting drivers' ease of turning left. However, this would result in drivers being able to turn across the cycle lane at their normal speed, and following their normal path, with minimal distance in which to respond to cyclists emerging from the segregated lane. These problems would be exacerbated where drivers are paying less attention to cyclists as they approach, because they are segregated, or if the driver assumes they will have priority at the junction.

It is important to note that where participants commented on potential conflicts with cyclists at the junctions many refer to cyclists in blind spots when turning left into the side-road, which will be a particular problem when drivers are able to take a turning path that encroaches into the cycle lane.

In conclusion: the greatest overall safety to all road users is therefore likely to be greater either with longer set-back distances i.e. 20 to 30m, which give drivers more time to notice cyclists and adapt to their presence on the road, or with a very short set-back distance, sufficiently close to the junction (5m or less in the trial example) so that the geometry is tightened leading to reduced turning speeds and changing the path of turning vehicles so that they cross the cycle lane in a more perpendicular path, thereby giving the driver better forward visibility of the cycle lane. These two situations are consistent with the two distinct design approaches adopted in the design practice sin countries such as Denmark and the Netherlands, although it is important to bear in mind important contextual differences such as the different priority rules applying to vehicles turning across cycle tracks adjacent to the highway (see Section 1.2).

The fact that a large proportion of drivers did not notice the different set-back distances suggests that more needs to be done to highlight the end of segregation, and so draw drivers' attention to the presence of unsegregated cyclists on the carriageway. Furthermore, the assumption by a few drivers, even if a tiny minority, that cyclists would always have to give way to them is potentially dangerous and may require further investigation. This is of particular relevance to the short set-back distance situations where turning drivers have to give way to a cyclist crossing their path, as distinct from the merging situation that applies with the longer set-back distances. A bollard, or change of lane colour etc. would also help address the concern expressed by many participants that they might clip the kerb with short set-back distances.

7 Conclusions

From the results of these trials it is concluded that two different strategies can then be considered:

1. Bring segregation very close to the turning (<5m, depending on local circumstances), sufficient to reduce the turning radius and so reduce turning speeds and position turning vehicles at right angles to the path of cyclists (this is similar in principle to the use of continental geometry at roundabouts). This would be most appropriate where geometry is already tight and vehicle speeds comparably low on the main road and the side road, or where other measures to achieve this will also be implemented.
2. End the segregation at least 20 m from the junction, giving cyclists sufficient space to re-introduce themselves into the traffic flow and for drivers to adapt to their presence. This would be more suitable where traffic speeds are higher and tight turning geometry is not considered to be appropriate. Nonetheless, speed reduction measures may still be needed in the vicinity of the junction to reduce the risk of collisions.

The range in between, 10 to 15 m, should be avoided as this constrains cyclists while leaving vehicles' turning path and speed unchanged. Where traffic speeds are higher than those found in the trial (~20mph to 30 mph), a precautionary approach would be to have longer set-back distances to give cyclists more time to control their position and for drivers to become aware of them.

Longer segregation set-backs will also be necessary if cyclists also need to turn right at a junction, or some other means provided to allow them to leave the segregated lane and position themselves appropriately. Although not part of the current trial, future trials could consider where this could be a role for intermittent segregation methods or other 'light' separation methods such as pole “Wands” or low profile methods such as the Zicla™ Zebra units.

The two design strategies summarised above are consistent with the approaches identified in the review of design practices in other countries (Section 1.2 of this report and Annex 1). However, when considering the application of international practices to the UK it is important to take account of important contextual differences, in particular the different priority rules that apply in the Netherlands and Denmark for example, so that drivers in those countries are used to giving way to cyclists when turning across adjacent cycle tracks.

Given the qualitative feedback suggesting some confusion over priorities and the interpretation of road markings at the end of the segregated section, further consideration should be given identifying the most effective treatments, which could include the use of bollards, termination markings or signs, or different coloured surfacing. In Denmark, for example, blue surfacing is used selectively across some junctions, to highlight the presence of cyclists, and not in kerbside lanes, whereas in this trial the whole length of the cycle lane was marked with green paint, whether segregated or not. On-street trials should be considered to assess the effectiveness of different markings and exit treatments. There may also be a role for a publicity campaign to alert drivers turning into side-roads to the need to be aware of cyclists.

Finally, this study has not considered the network operational impacts of implementing kerb segregation in relation to maintenance issues such as cleaning, vehicle impact, and winter service provision. It is recommended that these are investigated prior to widespread implementation to understand the potential impact on user safety, usage and maintenance budgets.

It is important to recognise that any off-street trial inevitably has its limitations and it cannot be assumed that the behaviours reported here would be replicated in a real street environment. The findings of this trial should not therefore be regarded as design guidance; further experience from on-street trials will therefore be needed before more definitive design recommendations can be made. As these trials were undertaken on roads with speeds lower than 30mph, it is suggested that any initial on-street trials of the short set-back distances are carried out on roads with similar speeds. Initial trials of short set-back distances should ensure that the set-back distance is sufficiently short, taking account of the geometry of the junction, to restrict the path and speed of turning vehicles to below 20mph (comparable with the off-street trial conditions). Where traffic speeds are higher than those found in the trial (which were typically 20 mph to 30 mph), a precautionary approach would be to consider longer set-backs to give cyclists more time to control their position and for drivers to become aware of them.