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DRAFT PROJECT REPORT RPN751

Off street trials of a Dutch-style roundabout

Cycle Facility Trials, Work Stream 2: Off-street trials of the safety implications of a Dutch-style roundabout with orbital cycle track

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Executive summary

Introduction

This report presents the safety findings of a series of off-street trials of a 'Dutch style' roundabout with an orbital cycle track, conducted at TRL during 2013. The trials were part of a wider programme of off-street trials of innovative cycling infrastructure commissioned by Transport for London (TfL) to provide evidence to inform the implementation of the Mayor's Vision for Cycling (GLA, 2013).

There is evidence to show that roundabouts present particular risks for cyclists, requiring them to adopt assertive riding positions to avoid the risk of various types of collision associated with entering and exiting the roundabout. A review of the role of infrastructure in cycle accidents carried out by TRL for DfT reviewed a number of studies in the UK and elsewhere and concluded that "there is a convincing body of evidence that roundabouts are a particularly risky junction type for cyclists" (Reid & Adams, 2010 p.30). It identifies continental approaches to roundabout design as methods for reducing the risk to cyclist, as well as the signalisation of roundabouts.

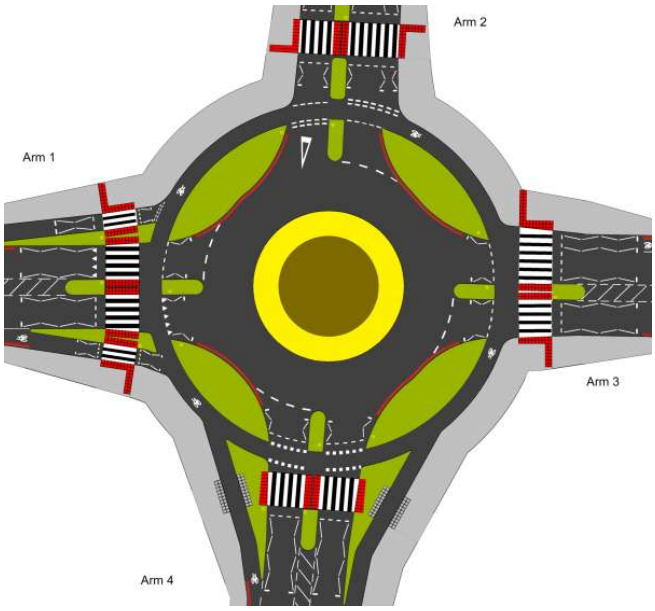
Because roundabouts are perceived by many cyclists as presenting a high risk, they are among the types of infrastructure that are likely to deter people from cycling. TfL are interested in exploring the potential for a roundabout that all types of cyclist would feel comfortable using, and hence commissioned TRL to undertake these trials.

The trials were designed to research the safety implications for cyclists. While it also involved other vulnerable road users like pedestrians as trial participants, the safety implications for these groups were not the subject of the research, and no research literature on the impacts of roundabouts on pedestrians was examined.

In addition to the safety trials, a series of capacity trials were designed to investigate the capacity implications of implementing this design of roundabout in the UK. A separate report has been generated from these capacity trials (Emmerson and Vermaat, 2014), but they have also provided some input to this safety report. A simulator trial on cognitive loading on drivers was also undertaken; see Novis and Reeves (2014). It should be noted however that this report should be read in conjunction with the Capacity report (PPR752) to ensure that the designer fully understands the design criteria and impacts of these.

Overview of the Roundabout and Trials

The roundabout layout used for the trials is based upon one of several types of roundabouts that can be found in the Netherlands. It draws upon the CROW (Netherlands) cycling infrastructure design guidance, and uses 'continental geometry' (short turning radii to reduce speeds and a single circulating vehicle lane) and also has a kerb-segregated cycle track at carriageway level, orbiting the roundabout, with priority for cyclists across the entry and exit lanes. Several different entry/exit arm treatments were tested.



The segregated cycle track is used to keep cyclists away from circulating vehicular traffic. While this forms part of the system of segregated cycle tracks commonly used in the Netherlands, it is also used at roundabouts in urban environments where cyclists typically share roads with other traffic.

A series of trials sought to establish the ways in which cyclists, pedestrians and car drivers understood, interpreted and used this particular type of 'Dutch style' roundabout, so that its safety impacts could be assessed. This research will therefore provide evidence as to users' comprehension of priorities and if regulatory changes will be needed to safely implement this infrastructure in the UK.

For the first trials (individual and car/cycle interaction), the roundabout used the standard Dutch road markings ('shark's teeth' instead of dashed lines as a give way marking) at the crossings of the entry and exit arms; subsequent trials used predominantly standard UK markings, adapted where necessary to take account of the limited road space available in this layout (which was designed to fit within the footprint of an actual London junction) and changed cycle priority on exit. The layout with UK markings is shown here. It can also be seen that the four arms have slightly different geometries, these being:

- Arm 1: Cyclists approach in a kerb-segregated cycle track within the carriageway which connects with the segregated orbital track. Cyclists also exit the orbital cycle track using a segregated cycle track.
- Arm 2: Cyclists approach in a mandatory cycle lane with a fairly sharp left turn into the orbital cycle track encouraged by an island which is shaped to direct the cyclists into the segregated orbital track. When exiting, cyclists leave the orbital cycle track taking a fairly sharp left turn directly into the main carriageway.
- Arm 3: Cyclists approach within the vehicle lane on the carriageway, with a fairly sharp left turn into the orbital cycle track. The island separating the cycle track from the main carriageway is neutral in terms of directing cyclists into the orbital segregation. When exiting, cyclists leave the orbital cycle track taking a fairly sharp left turn into a mandatory cycle lane.

- Arm 4: Cyclist approaches roundabout in a normal vehicle lane, with a segregated track leading to the orbital track turning off to the left. Cyclists leave the orbital track in a segregated cycle track which eventually merges with the main carriageway.
- On arms 1, 3 and 4 the zebra crossing and cycle crossing are immediately adjacent to each other whereas on Arm 2 there is a car length gap between the zebra and cycle crossing

Trials Methodology

A series of trials of increasing complexity were run, starting with trials involving only one type of user group at a time (e.g. cyclists, drivers etc.). Following these individual trials, further trials investigated how different users groups interacted, ending with trials involving cyclists, car drivers and pedestrians all using the roundabout at the same time.

Data gathered during these trials was analysed both qualitatively (through questionnaires and focus groups) and quantitatively (through analysis of video footage).

In addition, a simulator trial examined the behaviour of drivers using the roundabout with a higher density of traffic than was possible to achieve safely or logistically using the test track.

Key Findings

In general road users of all types found the roundabout easy to use, and perceived it to be safe, although there was some concern expressed by participants about the lack of understanding about priorities. There was a near-universal acceptance that cyclists would enjoy safety benefits from roundabout designs such as the one trialled, mainly as a result of segregation. Around half of participants thought pedestrians would benefit, and around half thought that drivers would benefit.

On exiting the roundabout, participant feedback indicates that it is not clear whether cyclists had priority over motor vehicles where they re-joined the carriageway. The trials indicated however most drivers did give way to cyclists and indicated that they would be prepared to do so, even though the car drivers had right of way.

Road users mentioned frequently that education and information campaigns would be needed if such roundabouts were introduced on real roads.

The majority of cyclists reported that they would be likely to use the orbital cycle track (in preference to the road) when in heavy traffic, although some more confident cyclists did express concern about its narrow width and high kerbs making overtaking more difficult and risky. Confident cyclists were also more likely to choose to use the main vehicle lane, particularly when turning right or going straight on, to minimise the distance travelled.

A potential risk area was identified for large vehicles leaving the roundabout, where drivers indicated that they found it difficult to see cyclists on the orbital cycle lane. The scale of this problem is not well understood, and a short literature review found that there is little available research or guidance in this area.

On the approach to the roundabout, conventional UK priority rules for roundabouts apply, so drivers should be expecting to give way to traffic circulating the roundabout, even if on a cycle track rather than the main carriageway. However, it was found that car drivers were far less likely to recognise the priority of a cyclist in the orbital track

when entering the roundabout than when exiting, even though drivers exiting a roundabout in the UK would normally not expect to have to give to anything.

There was confusion as to the priority between cyclists and pedestrians on Arm 4 where the zebra crossing did not extend to the cycle track (which incorrectly seems to imply priority for pedestrians), and this was singled out for criticism by participants.

The entry to Arm 3, which had a sharp turn into the orbital cycle track, was the least liked by cyclists and rated as the least safe.

The Arm 2 exit, where cyclists exited directly into the path of exiting cars, was rated as the least safe and least liked by cyclists.

Conclusions and discussion

Given the findings from the current programme of trials, the following conclusions can be drawn:

1. The geometry used in Arm 1 (and possibly Arm 4) should be the priorities for on-road trialling, where road space is available, given their generally better performance in both the measured priority violations and users' perceived safety and preference in the off road trials. In addition, the full width pedestrian crossing markings (i.e. across the entrance and exit cycle track, as in Arm 1) significantly clarified priorities.
2. Arms 2 and 3 (particularly the entrance geometry of both and the Arm 2 exit) should not be used for on-road trials without considerable redesign, although such an approach may need further consideration where available land precludes the use of those on Arm 1 and 4.
3. Given the limitations of the research as well as the findings a precautionary approach would be to conduct initial on-street trials at locations where traffic flows are comparatively low (especially of HGVs) and cycle and pedestrian flows are comparatively high, so that drivers expect their presence.
4. Any trial should be accompanied by extensive publicity, including temporary road signs, and public information work, to maximise the chances that a given road user will know what to expect of the infrastructure in terms of priorities.
5. Monitoring and evaluation of the ways in which people use the infrastructure, and the ways in which they perceive it, should follow the same basic approach as used in the trials described in this report, so that issues with implementation can be identified.
6. Cycle priority reinforced on the roundabout exits by clear markings and/or signs made priorities clearer for users; users expressed a preference for further methods to highlight the cycle crossing, such as coloured surfacing and speed reduction at the crossings such as raised tables. There is evidence that Dutch "shark's teeth" markings were considered clearer than standard UK "give way" lines, and a full sized UK "give way" triangle was clearer still.
7. Visibility of cyclists circulating on the cycle track from HGV's was highlighted as a key concern which should be carefully considered. While there is a lack of research into this issue, it is noted that this type of roundabout is in use in the Netherlands.

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1 Introduction

This report presents the results of a series of off-street trials of a 'Dutch style' roundabout with an orbital cycle track, conducted at TRL during 2013. The trials were part of a wider programme of off-street trials of innovative cycling infrastructure commissioned by Transport for London (TfL) to provide evidence to inform the implementation of the Mayor's Vision for Cycling (GLA, 2013).

Ten separate trials primarily concerned with safety were conducted on the roundabout (listed in Section 4). This report brings together the findings from the series of trials, summarising key findings and drawing overall conclusions. The detailed findings of each individual trial are presented as Appendices to this report.

Trials were also conducted that investigated the impacts of the trial design on traffic capacity; the results of these trials are presented in a separate report "PPR752 Dutch-style Roundabout Capacity" (Emmerson and Vermaat, 2015).

2 Background

2.1 Roundabouts and cyclists

In general, roundabouts are considered to be safe. Kennedy, Peirce and Summersgill (2005) have noted that in terms of overall safety benefits "All countries have found roundabouts to be a relatively safe form of junction" (p2) with reasons for this summarised as follows (NCHRP, 1998, cited in Kennedy et al., 2005):

- Reduced speeds / increased awareness because of need to deflect from ahead path
- Low number of conflict points at a roundabout compared with other junction types
- Separation of conflict points
- One-way operation of circulating carriageway

However, despite their good overall safety record, roundabouts have long been identified as particularly problematic for cyclists. Davies, Taylor, Ryley and Halliday (1997) for example suggest that roundabouts have long been known as "…one of the most hazardous junction types for pedal cyclists and motor cyclists" (p3). Similarly Lawton, Webb, Wall and Davies (2003) report that cyclists "…often find large and busy roundabouts difficult to negotiate safely and perceive themselves to be highly vulnerable compared with the motorist" (p3).

Research on accidents suggests that such concerns are well founded. For example Kennedy et al. (2005) report that although before/after studies have demonstrated large reductions in all types of collision when junctions of other kinds are converted to roundabouts, the accidents showing the smallest reductions are those involving two-wheelers. Morgan (1998) cites Layfield and Maycock (1986) and Kennedy, Hall and Barnard (1998) as having demonstrated that a high proportion of cyclist collisions at roundabouts involve a circulating cyclist with priority being struck by a motor vehicle entering the roundabout.

A review of the role of infrastructure in cycle accidents carried out by TRL for DfT reviewed a number of studies in the UK and elsewhere and concluded that "there is a convincing body of evidence that roundabouts are a particularly risky junction type for cyclists and that the speed of motorised traffic through roundabouts is a good proxy for risk" (Reid & Adams, 2010 p.30). It identifies continental approaches to roundabout design as methods for reducing the risk to cyclist, as well as the signalisation of roundabouts.

2.2 Continental roundabout geometry

In understanding how to approach roundabout design from the perspective of cyclist safety it is worth considering the differing philosophies adopted historically in the UK and in Continental Europe. Brown (1995, cited in Davies et al., 1997) has suggested that in the former case a focus on maximising capacity has been pursued, while in Continental Europe roundabouts tend to have been introduced with safety as the primary concern (Schoon & Van Minnen, 1994, cited in Davies et al., 1997). Specifically, cycle safety has become a particular concern in the Continental approach for some time now; Morgan (1998) for example reported on the findings from a study tour around several European countries (Denmark, Germany and the Netherlands) carried out in May 1994. One finding from the tour was that traffic engineers in these countries had begun to explore ways of introducing more cycle-friendly designs.

Some of the design characteristics of so-called 'continental style' roundabouts are summarised by Davies et al. (1997) and include:

- Arms that are radial (perpendicular) instead of tangential to the roundabout centre
- Single lane entries and exits (widths 4-5m)
- Minimal flare on entry

The differences in geometry can be clearly seen in Figure 1. Note that this is not to scale, and the continental roundabout is shown with UK markings for clarity.

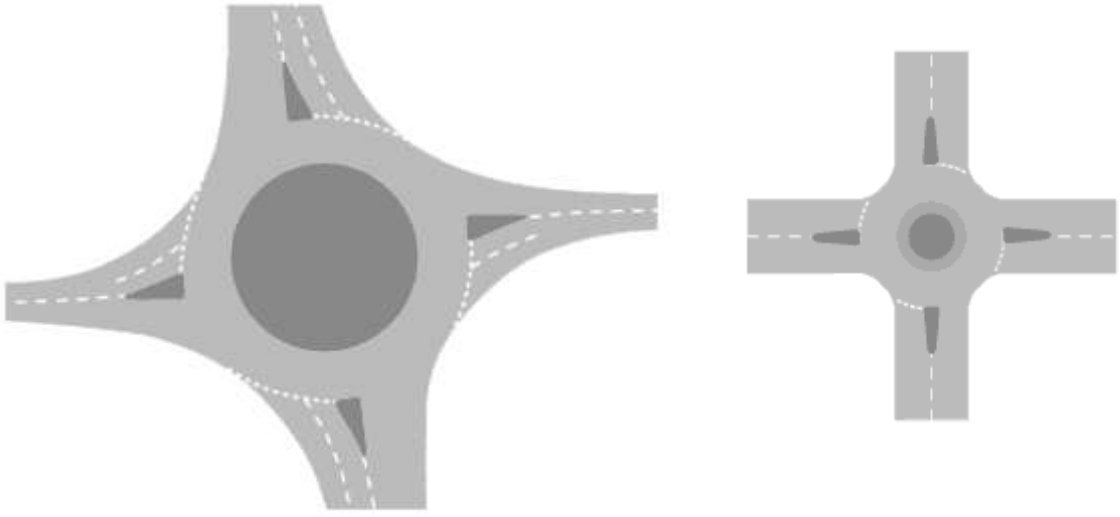


Figure 1: Comparison of UK Standard (left) and Continental (right) roundabout geometries

Note that other roundabout designs are used in the Netherlands and elsewhere on the continent, including those with annular cycle lanes, "turbo" roundabout etc., and that in every country the detail of roundabout design and priority rules must be seen in the context of that country's traffic law. Note also that the continental style of roundabout is virtually identical to the UK "Compact" roundabout as descried in DMRB.

All of these measures (along with a single circulating lane) seek to slow down traffic and provide motorists with better views of cyclists who may be present, by placing them closer to the centre of drivers' vision when entering and exiting, rather than at the periphery. Lawton et al. (2003) reported on a small-scale pilot trial of four roundabouts across the UK, with various design characteristics evaluated as to their potential impact on cycle safety. These design characteristics included reductions in the number of entry and exit lanes, enlarged central islands to reduce circulating space, tighter geometry, and more radial arms. The authors concluded that overall the findings suggested that safety might be improved for cyclists by adding such features to UK roundabouts where conditions (particularly a low enough flow) are suitable, although they caution that sufficiently robust and larger-scale trialling would be required.

Such 'continental' approaches to roundabout design are now recommended in the most recent design guidance from DfT (Cycling Infrastructure Design, LTN 2/08, TAL 9/97) and TfL's London Cycling Design Standards.

2.3 Orbital cycle tracks (Dutch Style)

In addition to the different geometries described above, a further development in cycle provision at roundabouts, especially in the Netherlands, is the use of an orbital cycle track, segregated from the circulating lanes for motorised traffic, often having priority over vehicles entering or exiting the roundabout. Morgan (1998) noted that at such roundabouts "…this arrangement was working very well: the vehicles were stopping and the cyclists seemed confident that they would stop" (p1). The same author did note however that Dutch research had shown that there were some collisions on such roundabouts caused by vehicles failing to give way to cyclists. Morgan suggested that these developments (separate cycle tracks, and the best priority rules for these) should be monitored closely, along with research being carried out (in the UK) on the impacts of the various other (speed-reducing) measures. Since then the use of roundabouts with orbital cycle tracks has increased significantly in the Netherlands, and analysis by the Institute for Road Safety Research (SWOV) concludes that conversion of other types of junction to roundabouts with separate cycle tracks leads to reduced cyclist causalities (SWOV, 2005). However, even within the Netherlands there is still a wide range of roundabout designs, and a key distinction is between those where the cycle track crosses the roundabout arms with priority to the cyclists and those where priority is given to vehicles entering and exiting. Both approaches are used, with **cyclists more usually being given priority at lower speed roundabouts in urban areas**, while motorised vehicles are usually given priority on higher speed roads outside towns. However, some evidence suggests that on the larger roundabouts where priority is more usually given to motorised traffic, there are other design differences, in particular the Fietsberaad website shows examples of the cycle track being taken further from the

circulating carriageway and being more 'square' in form, making the crossings more perpendicular and improving sight-lines[1].

It appears that there are still differences of opinion within the Netherlands on which approach is to be preferred: SWOV has recommended that priority should be given to motorised traffic on the basis of analysis that concluded that this would reduce causalities, however others (such as Fietsberaad) have disputed this conclusion and argue that a consistent approach giving cyclists priority would be better understood by drivers, also noting that roundabouts with cycle priority are still safer than other types of junction.

[1] Source: www.fietsberaad.nl

3 Design of the trial roundabout

The roundabout used for the trials was based on one particular design that has become widely used in The Netherlands over the last two decades, described in the Dutch 'CROW' cycling infrastructure design guidance. It uses continental geometry (short turning radii to reduce speeds and a single circulating vehicle lane). It also has a kerb-segregated cycle track at carriageway height, orbiting around the outside of the roundabout, with priority for cyclists across the entry and exit lanes. Several different entry/exit arm treatments were also tested.

Note that in this document we use the standard UK convention of referring to a physically segregated lane (e.g. by kerbs) as a "track", while a separate cycle or vehicle lane segregated only by a painted lane marking is referred to as a "lane". This convention is not necessarily followed in the appendices.

The series of trials sought to establish the ways in which cyclists, pedestrians and car drivers understood, interpreted and used the roundabout, so that its safety impacts could be assessed.

The geometric design of the roundabout remained unchanged for the duration of the trials, although two different designs of road markings were used. For the first trials (trial codes M5, M6a and M6b – see Section 4 for a full list), the full Dutch design was used, including the use of Dutch road markings. For subsequent trials (M21 onwards), the road markings were replaced with various forms of UK or combined UK/Dutch road markings. The design drawings were developed with TfL to fit the footprint of an example roundabout in central London.

The layouts for the roundabouts with Dutch markings and UK markings are shown in Figure 2 and Figure 4 respectively. Four designs of entry and exit layout were tested by having different layouts at each of the four arms of the roundabout. These were:

- Arm 1: Cyclists approach in a kerb-segregated cycle track within the carriageway which connects with the segregated orbital track. Cyclists also exit the orbital cycle track using a segregated cycle track.
- Arm 2: Cyclists approach in a mandatory cycle lane with a fairly sharp left turn into the orbital cycle track encouraged by an island which is shaped to direct the cyclists into the segregated orbital track. When exiting, cyclists leave the orbital cycle track taking a fairly sharp left turn directly into the main carriageway.
- Arm 3: Cyclists approach within the vehicle lane on the carriageway, with a fairly sharp left turn into the orbital cycle track. The island separating the cycle track from the main carriageway is neutral in terms of directing cyclists into the orbital segregation. When exiting, cyclists leave the orbital cycle track taking a fairly sharp left turn into a mandatory cycle lane.
- Arm 4: Cyclist approaches roundabout in a normal vehicle lane, with a segregated track leading to the orbital track turning off to the left. Cyclists leave the orbital track in a segregated cycle track which eventually merges with the main carriageway.

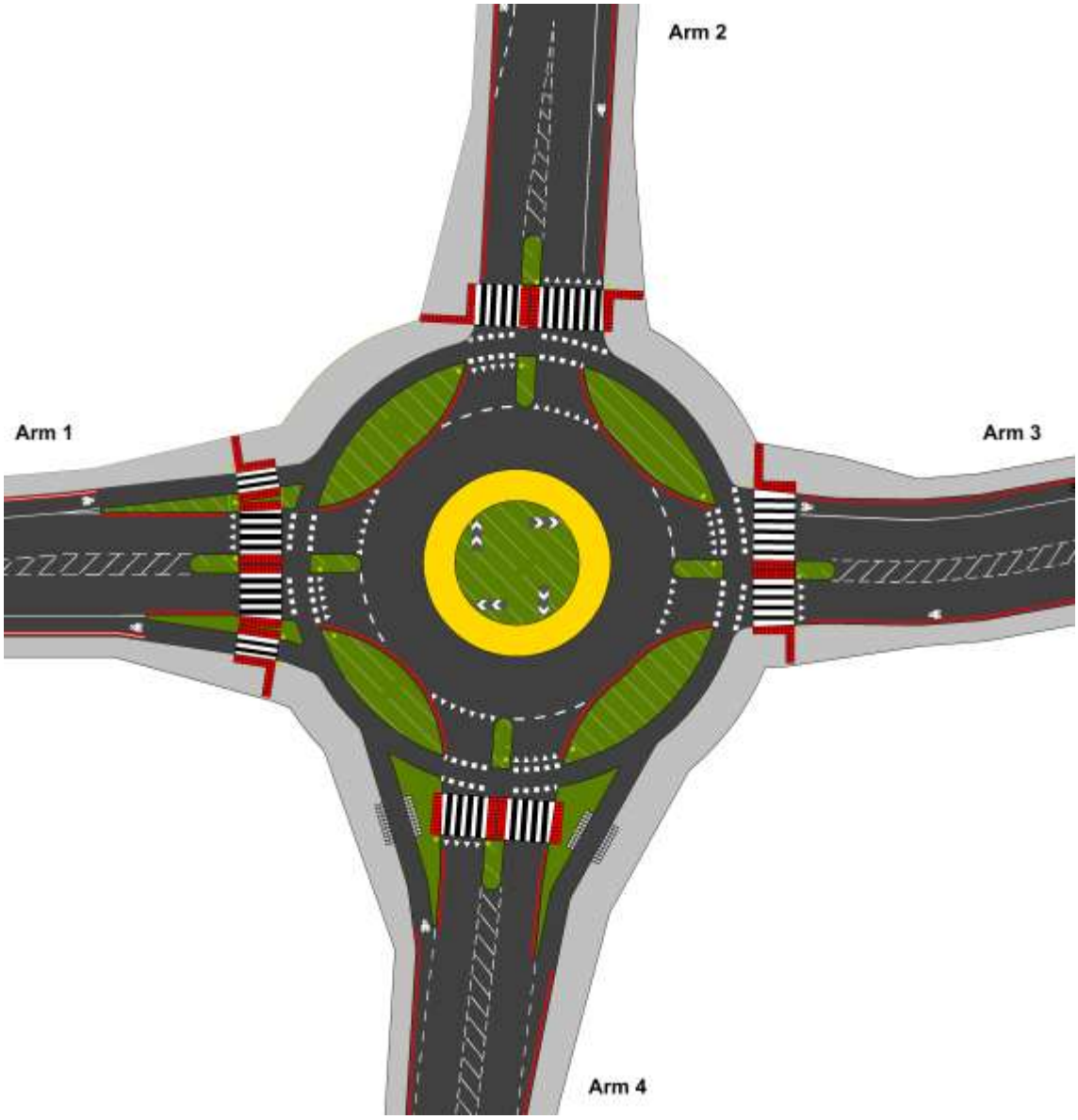


Figure 2: Layout of the Dutch-style Roundabout with Dutch road markings

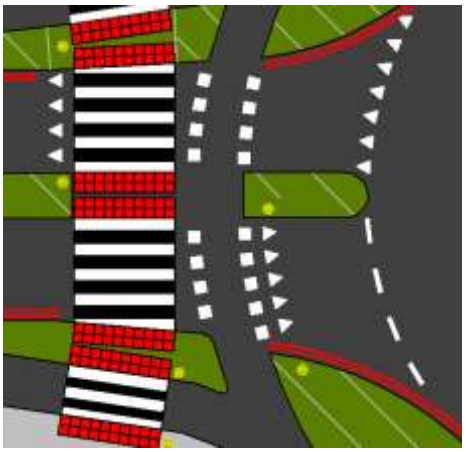


Figure 3: Detail of Dutch markings

An important aspect of the initial build of the roundabout is that it used standard Dutch-style road markings including 'sharks teeth' (white triangles) to show where drivers should give way and 'elephants feet' (white squares) to highlight the orbital cycle track as it crossed the entry and exit arms. These are shown in more detail in Figure 4 which illustrates the Arm 1 markings. This design was used to establish a baseline of participant behaviour using a design which is used in the Netherlands.

After the initial trials, the roundabout was changed to use UK style markings for subsequent trials. These are shown in Figure 4.

The changes between the Dutch and UK markings included the following:

- Application of zigzag markings on either side of the Zebra crossings
- Different markings delineating the orbital cycle track (single or double dashed lines rather than elephants feet/sharks teeth), although elephants feet were left on Arm 4 and sharks teeth left on the Arm 1 exit
- Double dashed "give way" markings were used on Arm 2 entry and exit to indicate cycle priority, reinforced on the exit by a "give way" triangle
- While the Dutch markings indicate the outside of the circulating car lane by a dashed line, UK practice only lines the entry-lanes, not the exit lanes
- Cycle symbols were painted on the orbital cycle track.
- Additional "give way" marking before the cycle track on the lane 2 exit

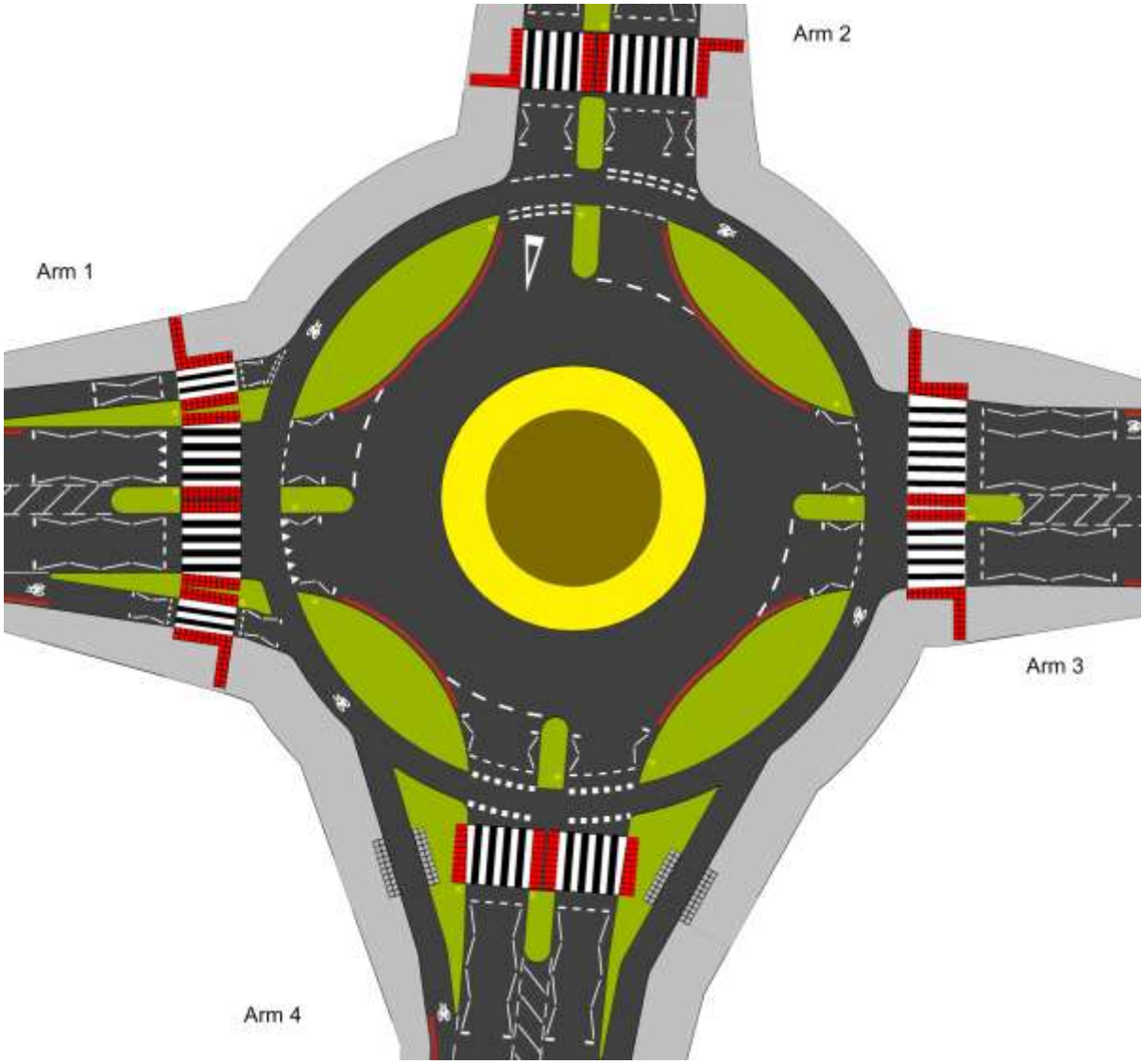


Figure 4: Layout of the Dutch style roundabout with UK markings

In addition, it was decided to move the zebra crossing on Arm 2 to introduce a 5m gap between the Zebra crossing and the cycle track crossing. This allows cars to negotiate the zebra crossing and the cycle track crossing separately.

4 Objectives of the trials

A key objective of the series of Dutch roundabout trials was to establish the ways in which cyclists, pedestrians and car drivers understand, interpret and use the roundabout, so that its safety could be assessed. Safety was assessed in terms of perceived safety impacts on individual users, potential conflicts between users, and reduced safety margins. Table 1 shows the way in which the trial programme evolved, listing each trial by its code (trial codes were assigned sequentially to each trial in the wider TfL trials programme, which is why they are not in a continuous sequence for this particular facility). Early trials examined the responses of single user groups, and then over the later trials different user groups were introduced so that interactions could be studied; early interaction trials used some 'controlled' participants (generally TRL staff) to ensure safety before later trials examined interactions between different user groups comprising members of the public.

Table 1: Individual Dutch roundabout trials

Trial code	Description	Objectives
M5	Individual user trials, Dutch markings	Understanding how car drivers, cyclists, motorcyclists and lorry drivers react to and use the roundabout individually
M6a	Cyclists interacting with drivers, Dutch markings	Understanding how cyclists react when encountering cars driven by controlled drivers
M6b	Drivers interacting with cyclists, Dutch markings	Understanding how drivers react when encountering cycles ridden by controlled riders
M21	Cyclists interacting with drivers, UK markings	Understanding how cyclists react when encountering cars driven by controlled drivers
M22	Drivers interacting with cyclists, UK markings	Understanding how drivers react when encountering cycles ridden by controlled riders
M25	Pedestrians and cyclists interacting, UK markings	Understanding how cyclists and pedestrians interact when encountering each other on the roundabout and zebra crossings
M26	Cyclists and cyclists interacting, UK markings	Understanding how cyclists using the cycle lane interact with other cyclists using the car lane on the roundabout
M27	Cyclists, pedestrians and drivers interacting, UK markings	Understanding the interactions between cyclists, pedestrians and car drivers when all three are using the roundabout/zebra crossings
M28	Capacity trials, UK markings	Understand the capacity implications of this type of roundabout design. A separate report is being produced on capacity, but these trials also provided input to the safety implications.
M37	Simulator trials	Understand how drivers react when using the roundabout in a higher density of traffic than could be achieved (safely or logistically) on the test track.

In this safety report we begin by considering the findings from the M27, M26 and M25 trials as these are the ones which include the most realistic interactions; in all these trials members of the public served as participants in all the user groups under investigation. As we address key findings from these trials, we report relevant supporting findings from earlier trials and from the M28 capacity trial and M37 simulator trial[2]. In this way we build up a summary of the key findings from the programme as a whole, focusing on identifying overall levels and perceptions of safety, and on identifying specific pitfalls and challenges that will require attention in any future on-road trials. The relative merits of the different arms trialled are also discussed.

[2] A specific issue around the visibility of cyclists for drivers of large vehicles was also examined – see Section **Error! Reference source not found.**.

5 Methodology

5.1 General method

All the on-track trials, other than the M28 capacity trials, followed a similar methodology:

- A number of participants (members of the public, typically 120–200) who had never seen the roundabout before were recruited.
- Each participant was asked to undertake a number of simple manoeuvres (e.g. "Drive/ride up to the roundabout and turn right"). They were given no instruction on how to use the roundabout, or what any signs or road markings meant.
- In the individual trial (M5) participants used the roundabout singly without any other users present.
- In the interaction trials, the participants either interacted with 'controlled' users (typically TRL staff) who were trained to engineer particular conflicts[3] (M6, M21, M22), or with other participants drawn from the public (M25, M26, M27).
- At the end of each manoeuvre, each participant was asked some simple questions relating to ease of use and safety during the manoeuvre.
- At the end of each trial, participants were asked to complete a comprehensive questionnaire on using the roundabout. The questionnaires include both closed and open-ended questions.
- About a quarter of participants in each trial were also asked to take part in focus groups where use of the roundabout was discussed in more depth.

The M28 trials were primarily designed to investigate the capacity implications of implementing this design of roundabout in the UK.

The M37 trial took place in the TRL DigiSim car driving simulator. This trial examined the behaviour of drivers using the roundabout with a higher density of traffic than was possible to achieve safely or logistically using the test track.

The methodologies for the individual trials are described in more detail in the respective findings reports- see Appendices.

5.2 Measures used

This section describes briefly the measures that were used in the various trials. Interactions were observed from video footage of the trials, while self-report data came mainly from the post-trial self-completion survey, and the short on-track survey. Focus groups provided more detailed qualitative data on many of the topics covered by the surveys.

[3] A traffic conflict is defined here as "an observable situation in which two or more road users approach each other in space and time to such as extent that a collision is imminent if their movements remain unchanged." (Amundsen & Hyden, 1977)

Observed interactions between road users

An interaction was defined as having occurred if two types of user (cyclist, car driver or pedestrian) came into close proximity (in time) within defined zones on the entrance and exit of the roundabout. The exact zones defined depended on the users in question, but always aligned to a part of the roundabout at which one of the road users should have priority (this varied with arm). Figure 5 shows the zones used in M27, with Arm 4 being used as an example. The interaction zones between cars and cycles (the small boxes) are those parts of the orbital track that cross the points at which cars need to enter and exit the roundabout. In all cases (for all arms) cyclists have priority at these points. The points of interaction between cyclists and pedestrians are those parts of the large marked boxes (brown) that cross the cycle track (in Arm 4 cyclists have priority here as there is no crossing marked, but in other arms the markings assign priority to pedestrians). The parts of the large marked boxes that cover the main pedestrian crossing define the interaction points between cars and pedestrians (at which pedestrians have priority in all cases).

In earlier trials, the precise zones of interaction were very similar to those defined in Figure 5; where important differences exist this will be highlighted in the findings.

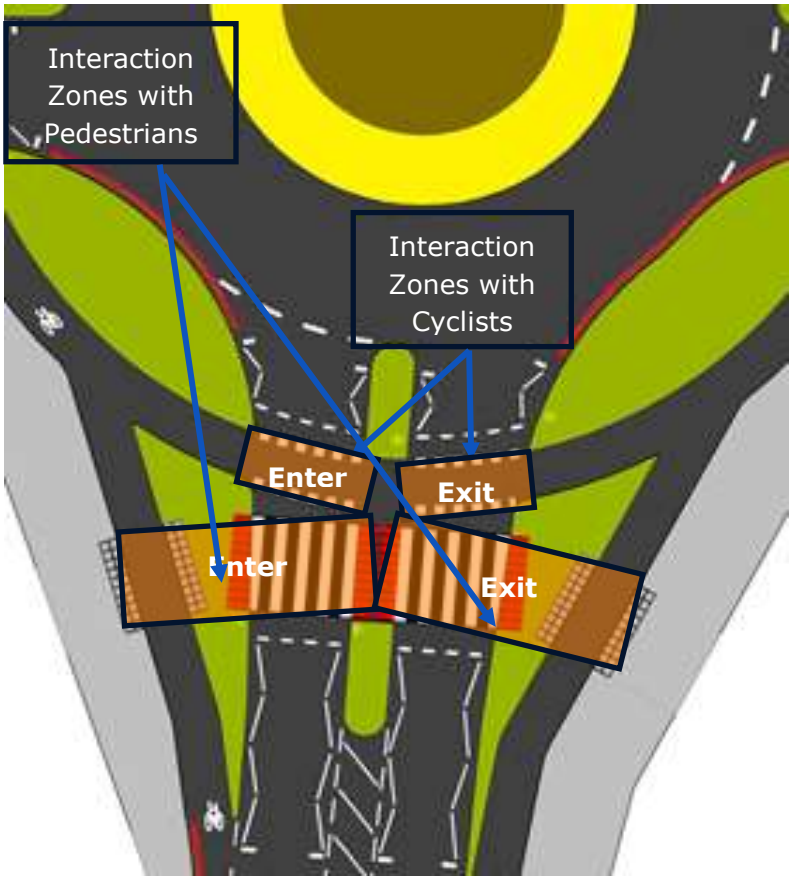


Figure 5: Interaction zones used in M27

Close proximity in the M27 trial was defined as meaning that two road users of different types had arrived at an interaction zone within three seconds of each other. In all earlier trials it was taken as meaning within two seconds of each other (since in earlier trials there were fewer road users present). In both cases the timeframe was picked such that in the judgement of the research team an interaction served as a good proxy for a 'conflict' as defined in footnote 1; it also presented a metric that could be measured from

the video without subjectivity (e.g. judging whether or not two users 'would have collided' when no collision did in fact occur)[4].

Self-reported understanding and intentions regarding priorities

Participants were asked various questions about the different stages of the roundabout (including the different arms), focused on their understanding and intentions in terms of giving way to other road users. The road users about which participants were asked depended on the trial, and the interaction points.

Self-reported feelings of safety and ease/difficulty of use

Participants were asked about how easy and safe they found using the roundabout at various points (for example entering and exiting the cycle lane, entering and exiting the orbital track or road on the roundabout).

Self-reported perceptions of benefits

Participants were asked various questions about what they saw as the likely benefits (including who would benefit, and who would not) of the roundabout design, if it were used in London on real roads.

Detailed qualitative data (from focus groups)

Focus groups covered discussion of the various topics covered in the surveys, and also invited unprompted comments about experience of the roundabout during the trials.

[4] We discuss specific interaction types and zones (for example a car leaving a roundabout and interacting with a cyclist moving across the orbital cycle track, see Table 6) but without considering in detail the manoeuvres (for example turning left or right) in which the vehicles concerned were engaged. Although the outcomes of these interactions (for example the extent to which correct priority was preserved) sometimes varied depending on manoeuvres in which the vehicles were engaged, there was no consistent pattern to this; for example, it was not always the case that cars turning right were more likely to violate priority of a cyclist than cars turning left. We have therefore combined manoeuvres when describing interaction outcomes.

6 Results

The results from all of the Dutch roundabout trials are synthesised in this section.

We begin in Section 6.1 by summarising the impressions people had of the roundabout as a whole. We then consider in Section 6.2 findings from the perspective of a road user's 'journey' through the infrastructure, splitting the findings into approaching and joining the roundabout, using it, and exiting.

The findings presented in this report are provided so that any on-road trials that follow from this work proceed in a way that is informed by the best data we currently have on 'overall impressions' and observed usage and specific feedback concerning the individual components of the layouts tested. Throughout the section, we therefore focus deliberately on highlighting those findings which signal specific challenges or 'pitfalls' identified through the work, to assist later on-road trials.

Because the approaches taken in Sections 6.1 and 6.2 do not lend themselves to a comprehensive and detailed presentation of all findings from the programme, the reader who is more interested in such a presentation is advised to consult the individual findings reports that are provided as appendices to this report.

6.1 How did people view the roundabout as a whole?

In this section we present the findings related to the overall Dutch roundabout concept. This includes impressions of safety, willingness to use the roundabout as intended (for cyclists) and what people thought the overall impact of the roundabout design would be.

The general perceptions of safety (section 6.1.1) are derived from the focus groups, and as such are qualitative. Subsequent sections are derived from analysis of questionnaire and video data and hence are more quantitative in nature.

6.1.1 General perceptions of safety

In general road users of all types found the roundabout easy to use, and perceived it to be safe. Cyclists tended to note that they found turning left to be safer and easier than riding straight on or turning right, while drivers tended not to mention differences between manoeuvres when discussing safety.

A consistent general positive theme throughout the programme was that cyclists (especially less confident, occasional cyclists) and drivers perceived that segregation for cyclists would offer a safety benefit. Pedestrians also noted that with segregation, they would know where to look for cyclists.

Another consistent general theme is that the minority of participants who rated the roundabout as unsafe or difficult to use tended to do so for reasons associated with tight turns and high kerbs in the orbital track (cyclists) or concerns on the roundabout exits associated with giving way to cyclists and holding up traffic (drivers).

Road users mentioned frequently that education and information campaigns would be needed if such roundabouts were introduced on real roads.

6.1.2 Willingness to use the roundabout as intended (cyclists)

The majority of cyclists reported that they would be likely to use the orbital cycle track (in preference to the road) when in heavy traffic. The proportion varied with the manoeuvre being undertaken, dropping from around 95% when turning left to around 90% when turning right or going straight on. The proportions dropped in lighter traffic (to around 90% turning left, around 80% going straight on, and around 75% turning right).

Less confident, occasional cyclists were more likely than regular, confident cyclists to say that they would use the orbital cycle track; in focus groups a number of more confident cyclists mentioned that when they were turning right and carrying straight on, the road itself would be a quicker and more convenient route, especially given some concerns about the high kerbs on the orbital track.

In all trials, a small number of cyclists suggested that they might use the orbital track 'the wrong way' (i.e. in an anti-clockwise direction) particularly if they were turning right.

6.1.3 Perceived impact

There was a near-universal acceptance that cyclists would enjoy safety benefits from roundabout designs such as the one trialled, mainly as a result of segregation. Around half of participants thought pedestrians would benefit, and just under half thought that drivers would benefit.

Around 30-40% of cyclists and around 20-25% of drivers and pedestrians suggested that roundabouts such as the one trialled would affect how much they cycle in London, nearly all saying it would make them more likely to cycle.

6.1.4 Visibility of cyclists for exiting large vehicle drivers

A key risk area for cyclists in London is their interactions with large vehicles. During the Capacity Trials, drivers of longer vehicles, (bus, coach, HGV and 18 tonne lorry) expressed severe reservations about the visibility of cyclists using the cycle lane:

> *"Vision is restricted on the nearside, unable to see if other cyclists are following [the first]"*
>
> *"Massive blind spot on left. 1st cyclist seen if 2nd waits 2 seconds extra as you pull away he then appears."*
>
> *"Cannot see cyclists on near side when stopped at exit, particularly if there is more than 1. Tend to see the approaching cyclists before stopping, but cycle lane then in blind spot and have no idea about following cyclists."*

This prompted a short literature review to establish if there was any research or evidence of blind-spot issues for drivers of longer vehicle in areas where this design of roundabout has been implemented. The review is included in the appendices to this report. This review was not able to find significant relevant evidence, but recommends further research to establish the extent to which this is an issue.

6.1.5 Understanding of Road Markings

Using the evidence from the trials, it is clear that that, for all markings, a large majority of drivers understood that they were expected to give way, and were willing to do so, or, where uncertain, gave responses that demonstrated caution.

Comparing the different arms with UK markings, it was found that on entry, there was little difference between the arms, and these differences are as likely to be due to layout differences as differences in markings. The layout differences are confounding factors which make it impossible to reliably differentiate the effects of different markings from those caused by different layouts.

On exit, Arm 2 gave the best performance in both preparedness and willingness to give way. This is not surprising as this has a very clear and generally well understood "give way" marking painted on the exit arm just before the "give way" line. This difference is emphasised by the fact that Arm 2 performed worst on the willingness to give way on exit with Dutch markings. Slightly more surprising is that Arm 1 with the "sharks teeth" marks performed better than Arm 3 with "give way" dashed lines on preparedness to give way. This seems to indicate that the "sharks teeth" may be clearer to drivers than standard UK "give way" lines.

The trials indicate that on entry standard UK markings are sufficient. On exit, the implementation of a standard UK "give way mark" may provide some benefit. The Dutch "sharks teeth" may provide some benefit over standard UK "give way" dashed lines.

It must be emphasised that the differences seen are small and not statistically significant. Two points are worth considering:

1. The trial suggests that there are no disadvantages to the Dutch markings either in terms of understanding, so may be worth considering because they offer some practical benefits over UK signs and lines in this application (compact, no signs needed)
2. The Dutch roundabout by itself presents drivers with an unfamiliar situation in which the priorities are the other way round to those they've come to expect where segregated cyclists cross a side road turning. So it is possible that the use of an unfamiliar marking could actually be helpful in drawing attention to an unfamiliar situation.

Lastly, no participants in the trials were instructed on the meaning of signs and markings before or during the trials, so the beneficial effect of a public information campaign before introducing new layouts, signs and markings cannot be estimated.

6.2 A journey through the roundabout from the user perspective

In this section, we discuss specific issues that arose from the programme of research on different sections of the roundabout, from the perspective of a cyclist's or driver's 'journey through' the infrastructure[5]. Findings are therefore presented in terms of approaching and joining the roundabout, using it, and exiting it.

[5] Findings unique to pedestrians are also considered, but for brevity in this report we only mention these as a matter of course explicitly in relation to interactions with cyclists, or when there are clear safety issues either in relation to their interactions with cars, or more generally.

6.2.1 Approaching and joining the roundabout

6.2.1.1 What happens when cars approach the roundabout?

Drivers rated the approach as being easiest for Arms 1 and 4, which had segregated cycle lanes.

When cars approaching the roundabout interacted with pedestrians on the pedestrian crossings pedestrian priority was sometimes violated (i.e. cars sometimes went before a pedestrian within the time-window defined for interactions – see Section 5.2). It should be noted that the approaches to the zebra crossings were implemented in full accordance with current regulations and design guidance, so all drivers should have been aware of the priorities.

The highest percentage of violation was for cars turning right at Arm 4, with 28% of cars violating priority of a pedestrian on the pedestrian crossing in this situation. High rates were also recorded for cars turning left at Arm 2 (26%) and Arm 3 (22%). Other figures varied between 1% and 14% with no obvious association with manoeuvre or arm. What is apparent from the data is that cars entering the roundabout violated pedestrian priority more often than those exiting it (see Section 6.2.3.1); this may have been related to the fact that car drivers were likely to be driving more slowly when exiting, as they would have been less familiar with the driving situation (i.e. having to be wary of cyclists in the orbital cycle track) and therefore exercising greater caution. Pedestrians noted in questionnaire responses and focus groups that they had some concerns about priority, and drivers also mentioned that they found exiting more difficult than approaching or joining the roundabout, which also supports this interpretation.

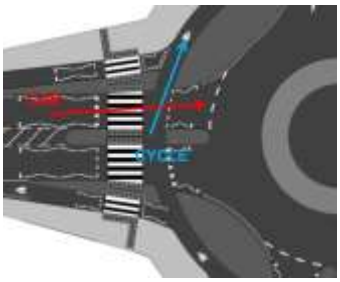
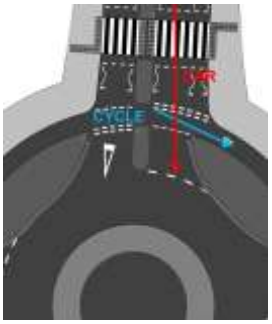
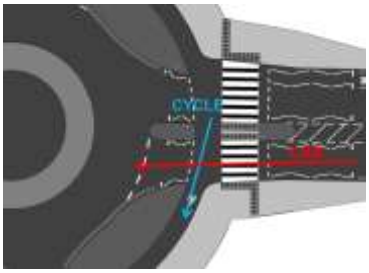
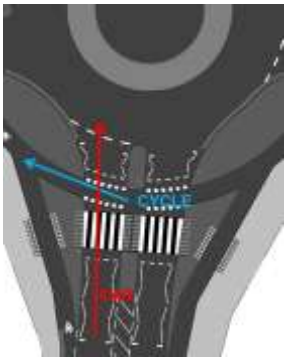
6.2.1.2 What happens when cars join the roundabout?

Table 2 shows for each arm the key interaction between a car entering the roundabout and a cycle on the orbital cycle track. It should be noted that in this situation, car drivers were effectively following standard roundabout priority rules for UK roads (give way to the right). What is noteworthy when these figures are compared with those in Section 6.2.3.1 is that **when entering the roundabout, car drivers were far more likely to violate the priority of a cyclist in the orbital track than when exiting the roundabout**. Arm 1 had the lowest rate at 14-37%. For other arms the rate was around 40% or more.

In all the trials in the programme, when drivers were asked about their intentions regarding giving way to cyclists on the orbital cycle track when joining the roundabout, the majority said that they would give way (typically around 90%), and an even greater majority said they were willing to give way to cyclists already crossing using the cycle lane (in excess of 95%). That their behaviour did not match this stated intention is intriguing. Although the evidence does not provide an explanation for this observation, it is important to bear in mind that joining a roundabout while giving way to the right is a highly practised action while being required to give way to cyclists on the orbital track when exiting is a completely novel behaviour on a completely novel design of infrastructure, so it would be expected that different behaviours would result.

Although Arm 1 has the lowest rate, it is difficult to draw firm conclusions regarding the absolutely level of priority violations (by car drivers on cyclists in the orbital cycle track) we might see in real-world implementations of the roundabout tested.

Table 2: Interactions with cyclists when cars enter the roundabout

Arm		Who has priority?	In what % of interactions was priority violated?
1		Cyclist	≈14-37%
2		Cyclist	≈52-61%
3		Cyclist	≈42-52%
4		Cyclist	≈38-44%

6.2.1.3 What happens when cyclists approach the roundabout?

The key interaction relating to cyclists approaching the roundabout is with pedestrians on the various parts of the crossing points (on the road on Arm 2 and Arm 3, and on the segregated cycle lane on Arm 1 and Arm 4).

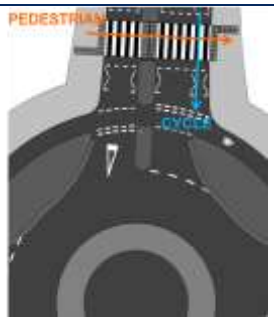
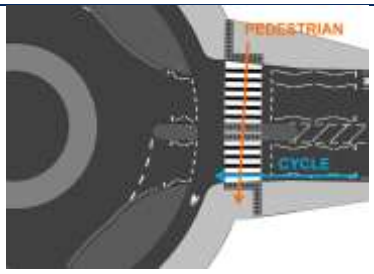
Table 3 shows this interaction for each arm. There was variability between the arms, with the greatest lack of clear priority occurring on the Arm 4 approach. On this arm pedestrians crossed the segregated cycle lane at a point without black and white

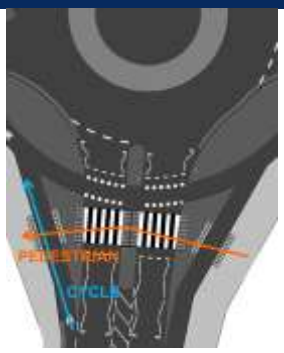
markings on the cycle lane surface, although tactile paving was present and the route was implied through the alignment with the marked pedestrian crossing on the road. Thus the marking signalled that on Arm 4 cyclists actually had priority over pedestrians. It is noteworthy that in nearly half of cases, despite having priority, cyclists allowed pedestrians to cross in front of them at this point.

The confusion over who had priority at this point on Arm 4 was evident in cyclists and pedestrians in both trials in which these two road user groups interacted (M27 and M25). Responses from questionnaires (backed up by focus groups) in these two studies confirmed that the majority of people (typically 60-70% from the questionnaire responses) were confused as to priority at this point, compared with Arm 1 where typically under 20% of people were confused.

Pedestrians also consistently rated this point as the least safe and most difficult place to cross, and it was a consistent 'outlier' in cyclists' discussions of the infrastructure; generally the infrastructure was well understood and well liked, but **this point on Arm 4 was generally not well understood and was singled out for criticism**, specifically for its lack of clarity.

Table 3: Interactions with pedestrians when cyclists approach the roundabout

Arm		Who has priority?	In what % of interactions was priority violated?
1		Pedestrian	≈18%
2		Pedestrian	≈13%
3		Pedestrian	≈6%

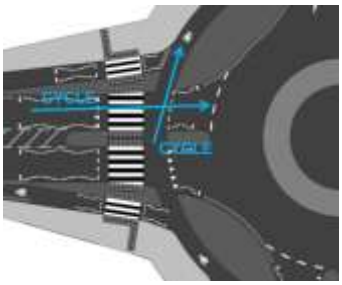
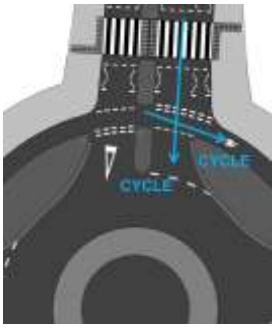
Arm		Who has priority?	In what % of interactions was priority violated?
4		Cyclist	≈45%

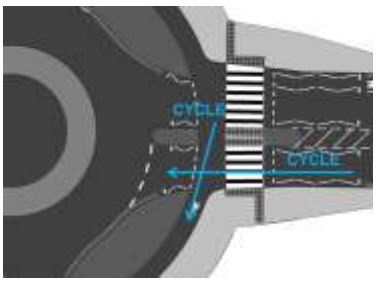
In general cyclists rated the approach to the roundabout as being easiest and safest on Arm 1 and Arm 4 (with the exception of the confusion over pedestrian priority mentioned above).

6.2.1.4 What happens when cyclists join the roundabout?

In M26 the interactions between cyclists joining the roundabout on the road, and cyclists crossing the exit in the segregated cycle track, were studied. Table 4 shows these data. Priority (of those on the cycle track) was violated in the M26 trial in around 17-32% of cases, depending on arm. Questionnaire and focus group responses confirmed that cyclists in the road had little understanding of who should have priority in this situation, and there was some variability between the arms.

Table 4: Interactions between cyclists joining the roundabout on the road and cyclists crossing the orbital cycle track

Arm		Who has priority?	In what % of interactions was priority violated?
1		Cyclist on orbital track	≈32%
2		Cyclist on orbital track	≈24%

Arm		Who has priority?	In what % of interactions was priority violated?
3		Cyclist on orbital track	≈17%
4		Cyclist on orbital track	≈24%

Cyclists ratings of safety and opinions gathered in focus groups revealed a number of specific issues with the different arms, when joining the orbital cycle track. These are summarised in Table 5.

Table 5: Specific issues associated with joining the orbital cycle track

Arm	Generally liked or disliked on exit?	Specific issues
1	Liked	Generally rated as easy and safe for joining.
2	Generally disliked	Sharp turn into orbital cycle track was often mentioned.
3	Universally disliked	Sharp turn into the orbital cycle track was mentioned consistently throughout programme as difficult and unsafe.
4	Liked	Generally rated as easy and safe for joining.

6.2.2 Using the roundabout

The feedback on using the roundabout tended to follow the general findings about the overall concept.

Cyclists in general liked using the orbital cycle track, although some more confident cyclists did express concern about its narrow width, high kerbs, and whether they would use it when turning right or continuing through the roundabout to go straight on.

Car drivers tended to mention a reluctance to 'stop' on the roundabout.

6.2.3 Exiting the roundabout

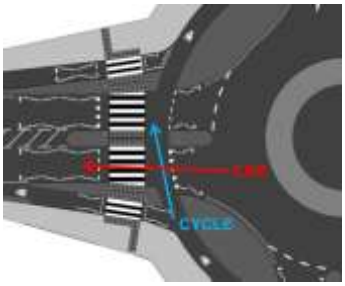
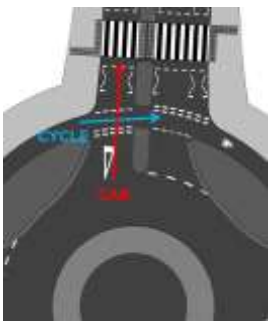
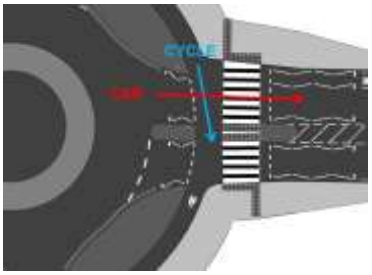
6.2.3.1 What happens when cars exit the roundabout?

Table 6 shows for each arm the interaction between a car leaving the roundabout and a cycle on the orbital cycle track that is carrying on across the exit. Cars almost always gave way to cyclists in this situation, but there were examples of conflicts; this was backed up by questionnaire and focus group findings from the M27 trial and from earlier trials, with the majority of drivers (but not all) reporting that they would be prepared and willing to give way to cyclists in this situation.

There was some variation in the extent to which the priority was violated (the cyclist had priority in all cases). Arm 1 would appear to have the lowest rate, and Arm 4 the highest.

Car/pedestrian priority reversals (i.e. the pedestrian having priority but a car driving over the pedestrian crossing before them) **were almost completely absent from all arms, except Arm 4** (6-11%).

Table 6: Interactions with cyclists when cars exit the roundabout

Arm		Who has priority?	In what % of interactions was priority violated?
1		Cyclist	≈3-4%
2		Cyclist	≈3-13%
3		Cyclist	≈4-6%

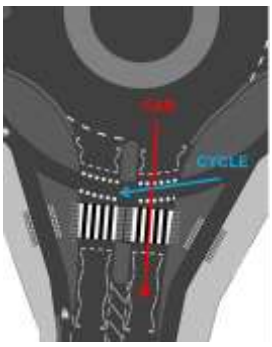
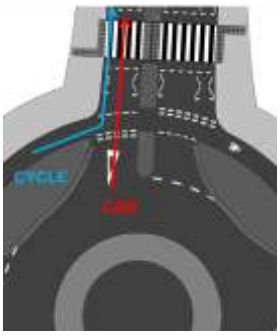
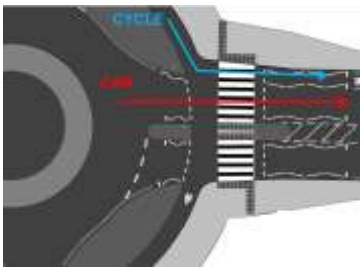
Arm		Who has priority?	In what % of interactions was priority violated?
4		Cyclist	≈14%

Table 7 shows another key interaction that happens on Arm 2 and Arm 3 only; this is when a car leaves the roundabout and a cyclist also leaves at the same exit, by having to turn from the orbital cycle track into the exit road. (Note that this interaction does not happen on Arm 1 or Arm 4 due to the segregated cycle track continuing off from the orbital track and merging with a cycle lane on the road after the exit area.)

The data (when compared with the data in Table 6) suggest that cars are more likely to interact with cyclists when the cyclists are exiting the roundabout, than when the cyclists are crossing the exit in the orbital cycle lane, at these arms. These arms received poor ratings from cyclists on exit and the interaction data may help to explain this.

Table 7: Interactions between cars and cyclists exiting the roundabout together

Arm		Who has priority?	In what % of interactions was priority violated?
2		Cycle	≈16%
3		Cycle	≈22%

The cycle priority over cars when cars exit the roundabout is reinforced via three different types of priority markings:

- On Arm 1 the cycle lane is bounded by Dutch-style Shark's teeth markings
- On Arm 2 the cycle lane is bounded by a UK style double dashed lane marking reinforced by the "give way" marking painted on the carriageway
- On Arm 3 the cycle lane is bounded by a UK style single dashed lane marking
- On Arm 4 the cycle lane is bounded by Dutch-style "elephants' feet" markings, reinforced by a single dashed lane marking.

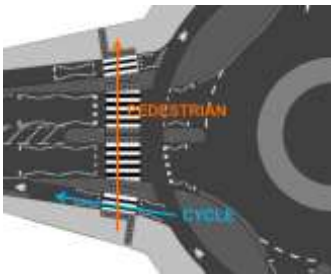
While it is clear from the analysis of questionnaires that UK road users do not have a clear understanding of the exact meaning of the Dutch-style markings, the majority of drivers (>65%) gave a "safe" response indicating that they would give way to cyclists. Also, when questioned about their intentions when leaving the roundabout, about 90% of drivers said they prepared to give way to cyclists, and about 95% said they were willing to give way to cyclists already crossing the car lane on the cycle track, with very little difference between the four arms. For both preparedness and willingness to give way, the markings used on Arm 2 scored better than the other arms by a small amount.

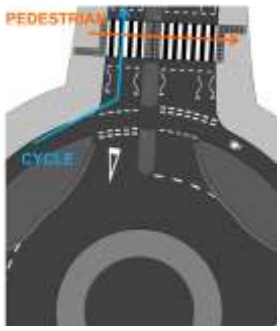
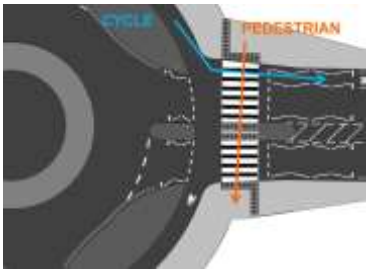
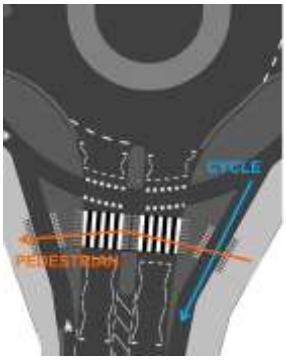
6.2.3.2 What happens when cyclists exit the roundabout?

There are two key interactions that were studied relating to cyclists exiting the roundabout. First (in M27) cyclists interact with pedestrians on the various parts of the crossing points (on the road on Arm 2 and Arm 3, and on the segregated cycle lane on Arm 1 and Arm 4). Second (in M26) the interactions between cyclists leaving the roundabout on the road, and cyclists crossing the exit in the segregated cycle track were considered. In this section we consider these two interaction types separately.

Table 8 shows the first of these interaction types. **Cyclists almost always gave way to pedestrians on Arms 1 to 3** (on which pedestrians had priority) with this again backed up by questionnaire and focus group findings from the M27 trial and earlier trials.

Table 8: Interactions with pedestrians when cyclists exit the roundabout

Arm		Who has priority?	In what % of interactions was priority violated?
1		Pedestrian	≈2%

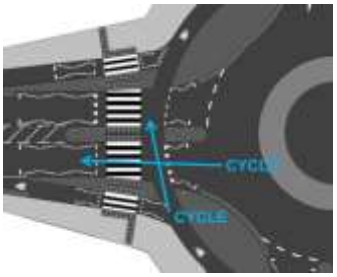
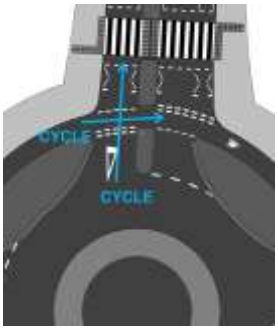
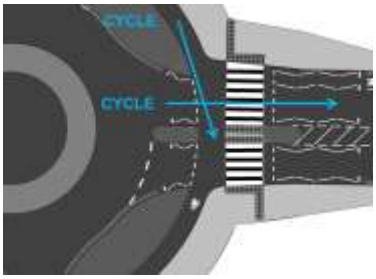
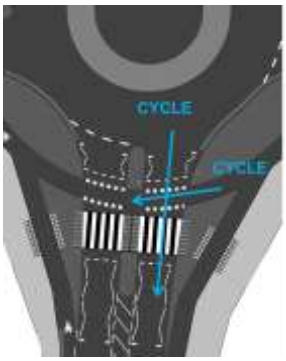
2		Pedestrian	≈6%
3		Pedestrian	≈6%
4		Cyclist	≈75% (Note: Many cyclists gave way to pedestrians so crossing acted as an informal style crossing)

As was the case with cyclists approaching and joining the roundabout the **clear point of confusion between cyclists and pedestrians occurred on Arm 4**, where cyclists crossed an unmarked (but implied) pedestrian crossing point in the segregated cycle lane on the exit. An even higher percentage of cyclists gave way to pedestrians (even though they did not need to) on the exit than on the entrance (75% versus 45%). The confusion about who has priority is probably because the pedestrians can see the zebra crossing over the vehicle lane only a short distance directly ahead of them and may naturally feel that the priority this gives them extends to the cycle track as well.

Table 9 shows the interaction between cyclists in the road exiting the roundabout, and cyclists on the orbital cycle track. Priority (of those on the cycle track) was violated in the M26 trial in around 26-34% of cases, depending on arm. Questionnaire and focus group responses confirmed that cyclists in the road had little understanding of who should give way to who in this situation, but there was no obvious difference between the arms.

Despite the rate of violation being higher in this interaction than for car/cycle interactions of the same type, it is worth noting that this interaction may be relatively rare in real-world use of the roundabout, given the high percentage of cyclists who say they would use the orbital cycle track. However, it may be worth ensuring that in any information campaigns that support further trialling, cycle/cycle priorities are highlighted to users to help minimise confusion.

Table 9: Interactions between cyclists exiting the roundabout on the road and cyclists crossing the orbital cycle track

Arm		Who has priority?	In what % of interactions was priority violated?
1		Cycle on orbital track	≈32%
2		Cycle on orbital track	≈26%
3		Cycle on orbital track	≈34%
4		Cycle on orbital track	≈32%

Cyclists' ratings of safety and opinions gathered in focus groups revealed a number of specific issues with the different arms, when exiting from the orbital cycle track. These are summarised in Table 10.

Table 10: Specific issues associated with exiting the orbital cycle track

Arm	Generally liked or disliked on exit?	Specific issues
1	Liked	Some mentioned tight turn from orbital cycle track into cycle lane on exit.
2	Universally Disliked	Sharp turn into traffic on exiting the orbital cycle track was mentioned consistently throughout programme as difficult and unsafe.
3	Generally disliked	Sharp turn viewed as difficult and unsafe.
4	Liked	Key issue mentioned was confusion over pedestrian priority.

7 Conclusions

This report has presented the results of a series of off-street trials of a 'Dutch style' roundabout with an orbital cycle track, conducted at TRL during 2013. It has attempted, deliberately, to summarise the key and consistent quantitative and qualitative findings from the programme of work, based largely on the most recent trials which involved full interactions between naïve cyclists, car drivers and pedestrians in various combinations.

The Report does not attempt to make direct comparisons with other types of facilities for a given location or set of circumstances or if a Dutch Style Roundabout is a more / less viable solution than other existing layouts.

The purpose of this report is to ensure that further trialling (on-road) of such designs proceeds in a way that is informed by the best evidence we have available of how different road users perceive and use such infrastructure. In this section we present the key findings, discuss limitations of the research, and draw conclusions pertinent to on-road trialling.

7.1 Key Findings

In general, perceptions of the roundabout design were positive. Cyclists and drivers especially suggested that segregation was a good thing for safety. Some concerns were raised by some users that high kerbs and tight turns for cyclists on some arms could be an issue. Information and education campaigns were noted as being necessary should on-road implementation proceed.

Cyclists generally expressed an intention to use the roundabout as intended, although for some cyclists (particularly those who are more confident) suggested that they might use the main road lane for carrying straight on and turning right.

Arm 1 appears to perform the best overall, particularly in terms of geometry. It had the lowest rates of adverse interactions between cyclists and cars on entry and exit, had good segregation on approach, a reasonably straightforward entry to the orbital cycle track, and was reasonably well-understood by cyclists in terms of what they were required to do with regard to pedestrians crossing the cycle track on entry and exit. Arms 2 and 3 suffered from poor feedback regarding tight entry and exit into and out of the orbital cycle track; Arm 2 in particular had poor feedback regarding safety on exit, due to it involving a tight turn directly into the traffic lane. Arm 4 received positive feedback in general, but suffered from a specific issue regarding pedestrian priority on the track on approach to and leaving the roundabout.

Regarding exit markings, Arm 2 with UK markings gave the best performance in both preparedness and willingness to give way. This is not surprising as this arm had a very clear "give way" marking painted on the exit lane just before the "double give way" line, despite that fact that this arm got the worst feedback (together with Arm 3) for the cycle exit due to the tight geometry.

7.2 Limitations

The key limitation of the current trial is that only one design of each arm was tested. It is entirely possible that some mixes of features from different arms would have been preferable to the individual designs tested.

It also needs to be borne in mind that almost all the trials had individual vehicle movements and interactions (rather than a 'traffic flow') at controlled speeds, and when road users were completely focused on the task at hand and had no other distractions. In addition users were carrying out manoeuvres repeatedly in the same general context, rather than encountering the infrastructure as part of a journey.

All of these limitations make it impossible to use the findings of the current set of trials as the basis of design guidance. Rather, these results can inform on-street trials that combined with other technical work could lead to design guidance.

7.3 Conclusions and discussion

Given the findings from the current programme of trials, the following conclusions can be drawn:

1. Where sufficient road space is available the geometry used in Arm 1 (and possibly Arm 4) should be the priorities for on-road trialling, given their generally better performance in both the measured priority violations and users' perceived safety and preference in the off road trials. In addition, the full width pedestrian crossing markings (i.e. across the entrance and exit cycle track, as in Arm 1) significantly clarified priorities.
2. The layouts used for Arms 2 and 3 of the trial roundabout (particularly the entrance geometry of both and the Arm 2 exit) should not be used for on-road trials without considerable redesign, although such an approach may need further consideration where available land precludes the use of those on Arm 1 and 4.
3. Given the limitations of the off-street trials a precautionary approach would be to conduct initial on-street trials at locations where traffic flows are comparatively low (especially of HGVs) and cycle and pedestrian flows are comparatively high, so that drivers expect their presence.
4. Any trial should be accompanied by extensive publicity, including temporary road signs, and public information work, to maximise the chances that a given road user will know what to expect of the infrastructure in terms of priorities.
5. Monitoring and evaluation of the ways in which people use the infrastructure, and the ways in which they perceive it, should follow the same basic approach as used in the trials described in this report, so that issues with implementation can be identified.
6. Cycle priority reinforced on the roundabout exits by clear markings and/or signs made priorities clearer for users; users expressed a preference for further methods to highlight the cycle crossing, such as coloured surfacing and speed reduction at the crossings such as raised tables. There is evidence that Dutch "shark's teeth" markings were considered clearer than standard UK "give way" lines, and a full sized UK "give way" triangle was clearer still.
7. Visibility of cyclists circulating on the cycle track from HGV's was highlighted as a key concern which should be carefully considered. While there is a lack of research into this issue, it is noted that this type of roundabout is in use in the Netherlands.

8 References

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Appendix A Summaries of Findings Reports

This appendix contains summary trial reports from the various trials held on the Dutch-style roundabout. More complete findings reports are included in a separate appendix to this report.

A.1 M5 Individual Trials summary findings

The M5 trials used the roundabout with Dutch markings. Four user groups (cyclists, car drivers, lorry drivers and motorcyclists) were asked to make defined manoeuvres on the roundabout. Their use of the roundabout was evaluated by means of questionnaires, focus groups and video analysis of the manoeuvres the made.

Analysis of the post-trial questionnaires found that:

- All four user groups found the roundabout easy to use with average scores between 8.0 and 9.4 on a scale of 1 (very difficult) to 10 (very easy)
- Left turns were the easiest and right turns the most difficult
- Lorry drivers found it the easiest, followed by car drivers, motorcyclists then cyclists
- About a third of cyclists said they would "consider" using the cycle track counter-clockwise when turning right? to save time in the absence of other traffic
- Many users did not correctly understand the Dutch road markings, but nearly all made "safe" assumptions about them

The focus groups for cyclists, car drivers and lorry driver (motorcyclists did not take part) found that:

- There was a great amount of information to take in when using the roundabout
- Participants were uncertain as to the meaning of the (Dutch) road markings
- Car and GV drivers agreed that this design of roundabout did encourage them to travel slower around the roundabout than around a conventional roundabout
- For cyclists, a segregated track on the roundabout approach made the entry to the roundabout easier; however it did force cyclists into the orbital cycle track.

Analysis of the video data found that:

- Given free choice, and in the absence of other traffic, most cyclists (>80%) used the cycle track when turning left, but only a third did when turning right
- Cyclists using the cycle track took longer than those using the main carriageway, even when turning left
- The time taken to negotiate the roundabout is broadly similar for cars, goods vehicles and motorcycles

A.2 M6a Cyclists Summary Findings Report, Dutch Markings

The M6a trials used the roundabout with Dutch markings. The primary objective of the trials was to establish the reactions of cyclists when encountering cars at various points on the roundabout. Cyclists were asked to make defined manoeuvres on the roundabout, while controlled car drivers engineered interactions with the cyclists at predetermined points on the entry, exit and circulating parts of the roundabout.

Analysis of the post-trial questionnaires found that:

- Understanding of Dutch markings was poor, but must users gave a "safe" interpretation (caution, give way etc)
- General understanding of how to navigate the roundabout was good, but there was some confusion about priorities
- Joining the cycle track around the roundabout was described as being more difficult and less safe at Arm 3 than at the others
- For cyclists leaving the roundabout, Arm 2 was felt to be the most difficult
- The cyclists were largely in favour of taking advantage of the cycle track around the roundabout
- A small minority of participants did not think any groups would benefit and made only negative comments about risks, confusion, delays and allocation of priority.

The focus groups found that:

- All groups of participants commented that there was a great deal of information to consider throughout the trial
- All participants expressed natural caution, and indicated that they would stop for vehicles even when they had the right of way if they were concerned the vehicle would not stop
- The majority of participants agreed that their preferred arms were 1 and 4 with arms 3 and 2 the least favoured, concurring with the questionnaire data
- The majority of participants suggested that the compulsory use of the cycle track on the roundabout would not be practical due to difficulties in enforcement

Analysis of the video data found that:

- In nearly all cases where cyclists on the orbital cycle track interacted with cars leaving the roundabout, the cycle was given priority
- Interactions with cars had virtually no measurable effect on cycle journey times
- Car journey times were increased by interactions with cyclists on all arms

A.3 M6b Car Summary Drivers Findings Report, Dutch Markings

The M6b trials used the roundabout with Dutch markings. The primary objective of the trials was to establish the reactions of car drivers when encountering cyclists at various points on the roundabout. Car drivers were asked to make defined manoeuvres on the roundabout, while controlled cyclists engineered interactions with the cars at predetermined points on the entry, exit and circulating parts of the roundabout.

Analysis of the post-trial questionnaires found that:

- Understanding of Dutch markings was poor, but must users gave a "safe" interpretation (caution, give way etc).
- Almost all of the drivers said that on approaching and leaving the roundabout, they prepared to give way to cyclists and would have given way if they had seen a cyclist crossing on the cycle lane.
- General understanding of how to navigate the roundabout was good, but there was some confusion about priorities.
- Drivers, like cyclists, found joining the roundabout to be more difficult at Arm 3 than at the other entry points.
- Almost all of the participants thought cyclists would benefit from the roundabout, many thought motorists and pedestrians would benefit, and a majority made positive comments.
- About half of drivers thought it would be easier for drivers to use this roundabout than an ordinary roundabout and over a third saying it would be more difficult.

The focus groups found that:

- Over half of participants suggested that there was either too much road furniture and markings or that they were not adequately explained.
- The road markings (elephants' feet and sharks' teeth) were unfamiliar to most participants creating ambiguity over whose right of way it was at the cycle crossings, although it was agreed markings should be used to reinforce signage.
- A common concern drivers had was not seeing cyclists approaching the crossing if they appeared out of their peripheral vision.
- An added concern is that currently whilst on a roundabout drivers give way to the right, however with the addition of the cycle track they would need to give way to the left as well (when exiting).
- Another common concern was for drivers stopping on the roundabout whilst giving way to cyclists, suggesting they would feel vulnerable if stationary on the roundabout,

Analysis of the video data found that:

- In most cases (88% on Arm 3 to 97% on Arm 2) cyclists on the orbital cycle track took priority over cars leaving the roundabout.
- Between 50% (Arm 3) and 100% (Arm 2) of cyclists leaving the roundabout took priority when interacting with cars also leaving the roundabout.
- Car journey times were increased by interactions with cyclists on all arms.

A.4 M21 Cyclists Summary Findings Report, UK Markings

The M21 (and all subsequent) trials used the roundabout with UK markings. The primary objective of the trials was to establish the reactions of cyclists when encountering cars at various points on the roundabout. Cyclists were asked to make defined manoeuvres on the roundabout, while controlled car drivers engineered interactions with the cyclists at predetermined points on the entry, exit and circulating parts of the roundabout. Apart from the change in road markings, the M21 trials were identical to the M6a trials.

Analysis of the post-trial questionnaires found that:

- Cyclists' general understanding of how to navigate the roundabout was good, but not all were confident that drivers would give way when cyclists had priority.
- Over half of cyclists going round the roundabout on the cycle track said they expected a driver approaching the roundabout to give way to them.
- Just over 60% of cyclists said they would expect a car approaching the exit to wait for them while almost 20% said they would wait for the car.
- Cyclists found that joining the orbital cycle track was more difficult at Arm 3 than at the other arms, and Arm 2 was the most difficult when leaving.
- The majority of cyclists were in favour of taking advantage of the orbital cycle track, particularly in heavy traffic, and were more likely to use it when turning left than when going straight or turning right.
- Just over a third of cyclists thought it would affect how often they cycle in London if there were cycle tracks like this on roundabouts there.
- Comparing results from M6a, more cyclists expected the car to wait for them in the trial with UK markings than with Dutch markings

The focus groups found that:

- Most participants were impressed with the road layout in the trial, found it easy to use and thought the road markings were self-explanatory. However a number remarked there were excessive road markings.
- There were concerns that drivers may not give way to cyclists and if they did this could lead to long tailbacks either across the roundabout or blocking the pedestrian crossing.
- Participants all agreed they liked the segregation between cyclists and vehicles and all felt considerably safer than on traditional roundabouts.
- Some participants expressed the opinion that, if implemented correctly, this concept would save lives and encourage less confident cyclists.

Analysis of the video data found that:

- In nearly all cases where cyclists on the orbital cycle track interacted with cars leaving the roundabout, the cycle was given priority. This was also the case when they both exited the roundabout at the same time.
- Interactions with cars had virtually no measurable effect on cycle journey times
- Car journey times were increased by interactions with cyclists on all arms.

A.5 M22 Car Summary Drivers Findings Report, UK Markings

The primary objective of the trials was to establish the reactions of car drivers when encountering cyclists at various points on the roundabout. Car drivers were asked to make defined manoeuvres on the roundabout, while controlled cyclists engineered interactions with the cars at predetermined points on the entry, exit and circulating parts of the roundabout. Apart from the change in road markings, the M22 trials were identical to the M6b trials.

Analysis of the post-trial questionnaires found that:

- Drivers' interpretation of how to navigate the roundabout was good but a small proportion did not understand that cyclists crossing the entry and exit points had priority over vehicles entering and leaving the roundabout.
- Some drivers mentioned stopping at the roundabout exit while cars give way to cyclists as an issue.
- Leaving the roundabout was rated as more difficult than joining it.
- Almost all of the drivers thought cyclists would benefit from the cycle lane round the roundabout and many thought motorists and pedestrians would benefit. The negative comments from drivers were mainly about safety for cyclists and motorists.
- Comparing results from M6b, the UK markings appear to have been associated with some improvement in participants' understanding of priority at the cycle crossings but there may also be scope for improving the UK markings.

The focus groups found that:

- The majority of participants felt that segregating cyclists and vehicles was a positive step which would benefit cyclist safety.
- Some participants commented they felt unsafe and vulnerable whilst waiting on the roundabout in order to give priority to cyclists before exiting.
- Some participants felt uncomfortable about having to give way to both the left and right, when usually a driver would just give way to the right on a roundabout.
- Participants felt that this design would encourage less confident cyclists and some suggested this would just add to the safety of existing cyclists.

Analysis of the video data found that:

- In most cases (between 91% and Arm 2 to 96% on Arm 3) cyclists on the orbital cycle track were took priority over cars leaving the roundabout.
- Between 65% (Arm 2) and 90% (Arm 3) of cyclists leaving the roundabout took priority when interacting with cars also leaving the roundabout.
- Car journey times were increased slightly by interactions with cyclists on all arms.

A.6 M25 Cycle-Pedestrian Interaction Summary Findings Report

The primary objectives of the M25 trials were to establish how cyclists and pedestrians interacted when using the roundabout and how cyclists and pedestrians interpreted the layout and markings. Cyclists and pedestrian participants were both asked to undertake predefined manoeuvres which were timed to cause them to interact at various points on the roundabout. This was the first trial in which two participant groups interacted on the roundabout.

Analysis of the post-trial questionnaires found that:

- When approaching the roundabout at Arms 1, 2 and 3 where there were marked zebra crossings across the cycle track, over 90% of cyclists understood who had priority.
- Going round the roundabout while pedestrians cross, most pedestrians (85%) understood correctly that pedestrians waiting away from crossings should wait for the cyclist.
- At the designated crossing points, most pedestrians (75 – 83%) correctly understood whether or not they had priority over cyclists.
- For cyclists entering the roundabout, Arm 3 was rated as more difficult and less safe than the other entry points. For cyclists leaving the roundabout, Arms 2 and 3 were rated as more difficult and less safe than the other exit points owing to the sharp turn into the road at both exits.
- For pedestrians, crossing the entry and exit points to the roundabout were rated to be more difficult and less safe at Arm 4 than at Arms 1 and 2.
- The majority of cyclists were in favour of taking advantage of the orbital cycle track, particularly in heavy traffic.
- Almost all cyclists said they thought cyclists would benefit from the orbital cycle track round the roundabout, and many thought that motorists and pedestrians would benefit.
- A majority of pedestrians said it was easier or much easier to use for people walking than an ordinary roundabout but 16% said it was 'more difficult' and 2% 'much more difficult'. Almost all pedestrians thought cyclists would benefit.

The focus groups found that:

- Participant cyclists with children were complimentary and liked the segregation between vehicles and bikes. Overall, participants felt that the cycle track would benefit cyclist safety and it was felt this would benefit cyclists in London.
- A number of participant cyclists commented that there was a lack of signage and road markings to indicate whether cyclists or pedestrians had the right of way.
- From a safety point of view, a number of the participants suggested they felt they were 'in a safe tunnel' and unaware of their surroundings because of the segregation. A further criticism was the height of the kerbs along the cycle track.
- Pedestrians generally felt the roundabout would contribute to the safety of cyclists, with a number of pedestrians suggesting they would be encouraged to cycle more if it was introduced.
- Pedestrians reported that on first approaching the roundabout they found the layout to be very hectic and one participant suggested it was visually 'hammering'. However, having navigated the layout a few times, they found the design straightforward and were able to navigate it.

- Pedestrians felt that the layout would contribute to safety in busy environments; however there was concern that on fast roads both cyclists and drivers may be less likely to give priority to pedestrians.

A.7 M26 Cycle-Cycle Interaction Summary Findings Report

The primary objective of the M26 trials was to establish how cyclists using the orbital cycle lane interacted with other cyclists using the vehicle lane (main circulatory lane) to go around the roundabout. Cyclist participants were asked to undertake predefined manoeuvres using either the main circulating carriageway or the cycle track which were timed to cause them to interact at various points on the roundabout. Only cyclists were present on the roundabout during these trials.

Analysis of the post-trial questionnaires found that:

- The majority of cyclists were in favour of taking advantage of the orbital cycle track in a busy town or city.
- In general, participants rated the roundabout as 'easy' or 'very easy' and 'safe' or 'very safe' to use, but a minority found it difficult and unsafe. Cyclists who found it easier than an ordinary roundabout mainly explained this was because they were separate from traffic and felt safer. Those who found it more difficult tended to say that the workload was greater, the priorities were uncertain, or that it is confusing or complex.
- On average 87% of cyclists said that when entering the roundabout on the road they prepared to give way to cyclists crossing, and 75% of cyclists said when leaving the roundabout on the road they prepared to give way to cyclists crossing.
- Cyclists found it easiest to enter the cycle track before the roundabout at Arm 1 and Arm 4 (the segregated lanes). It was found to be most difficult at Arm 3.
- Cyclists found it easiest and safest to leave the orbital track at Arm 4, and most difficult and least safe at Arm 2.
- Almost all participants thought that cyclists would benefit from the cycle track round the roundabout.
- One of the most commonly mentioned difficulties with using the roundabout was with understanding and complying with the priority for cyclists circulating in the orbital track.

The focus groups found that:

- Cyclists hold a variety of views regarding the layout of the 'Dutch' roundabout, with less confident cyclists preferring segregation between cyclists and vehicles while more confident participants preferred to remain on the main carriageway
- A number of participants indicated that it was unclear how to navigate the roundabout due to the ambiguous nature of the road markings.
- A number of participants expressed their concern about tailbacks during busy periods, particularly with regard to the positioning of the pedestrian / cyclist crossing close to the roundabout.

Analysis of the video data found that:

- A majority of cyclists not using the orbital cycle track gave priority to cyclists who were using the cycle track.
- In all interactions there tended to be a flow that obtained greater priority, and these were in line with standard conventions.

A.8 M27 Car-Cycle-Pedestrian Interactions Summary Findings Report

The primary objectives of the M27 trials were to establish how cyclists, car drivers and pedestrians interacted when using the roundabout and how they interpreted the layout and markings. Cyclists, drivers and pedestrian participants were both asked to undertake predefined manoeuvres which were timed to cause them to interact at various points on the roundabout. This was the only trial which simultaneously had pedestrians, cyclists and car driver participants using the roundabout.

Analysis of the post-trial questionnaires found that:

- The majority of cyclists were in favour of taking advantage of the orbital cycle track, particularly in heavy traffic.
- Almost all of the cyclists said that they prepared to give way to pedestrians crossing the cycle track where the crossing was marked as a zebra crossing.
- When deciding when to cross a segregated cycle tack, almost all pedestrians said they looked for cyclists and most said they noticed the cycle track.
- Where there was a zebra crossing on a cycle track, a majority of pedestrians understood the priority and said they expected the cyclist to wait for them to cross; where there was no zebra crossing on the cycle track, a majority of pedestrians correctly understood the priority.
- Where there was no designated crossing on the cycle track, the majority of pedestrians said they would wait for the cyclist before they crossed.
- On average 94% of drivers said they would have given way if they had seen a cyclist crossing on the cycle lane. Fewer drivers said they would give way to cyclists emerging from the orbital track to re-join the vehicle lanes.
- In general, participants rated the roundabout as 'easy' or 'very easy' and 'safe' or 'very safe' to use, but a minority said they found it difficult and unsafe.
- In traffic, cyclists rated turning left using the cycle track as the safest manoeuvre and turning right as the least safe.
- When compared with an ordinary roundabout, the majority of cyclists said it was easier to use. Cyclists who found it more difficult said they would need to get used to the layout, that the markings were unclear, corners were tight and workload greater.
- For cyclists, entering the cycle track before the roundabout was found to be most difficult and least safe at Arm 3, and for leaving Arm 2 was described as the most difficult and least safe. This is in line with previous trials.
- Almost all participants thought that cyclists would benefit from the roundabout, about half though pedestrians would benefit and just under half though drivers would benefit. The main advantages of the roundabout, mentioned by all groups, were the segregation of cyclists from traffic and improved safety.
- Pedestrians appreciated having zebra crossings at all of the arms of the roundabout. However where the pedestrian crossing over the cycle track was not marked as a zebra crossing (Arm 4), a number of cyclists and pedestrians were confused about who had priority, and the pedestrians found this crossing point to be the most difficult one.

The focus groups found that:

- Cyclists hold a variety of views regarding the layout of the 'Dutch' roundabout, with less confident cyclists preferring segregation between cyclists and vehicles while more confident participants preferred to remain on the main carriageway.

- Cyclists criticised Arm 3, which was noted to have a particularly tight entry point. Arm 2 was the least favoured exit design as participants felt the location for cyclists to merge with traffic was too close to the roundabout. However, Arm 1 was commended with the entry and exit points described as seamless.
- The majority of cyclists felt that the layout would contribute to cycle safety.
- A number of cyclists indicated initially it was unclear how to navigate the roundabout due to the ambiguous road markings and lack of signage.
- Confident cyclists suggested they would be tempted to use the carriageway, as they considered that the cycle track was narrow preventing overtaking.
- Drivers were concerned the layout could lead to gridlock or long tailbacks if drivers were expected to give priority to all cyclists and pedestrians.
- Drivers suggested the layout would benefit cyclists and pedestrians. There were mixed views on the impact on drivers.
- A number of drivers suggested they felt this layout would encourage more cyclists in London, particularly those with children or less confident cyclists.
- The majority of pedestrians suggested the roundabout would increase safety for cyclists, whilst frustrating drivers and slowing their journeys, but would have little impact on pedestrians. However there were concerns there could be tailbacks as a result of high volumes of cyclists and pedestrians.
- Pedestrians criticised the location of the zebra crossing. Whilst acknowledging that this was consistent with pedestrians' desire lines, there was concern that road users would not have sufficient time to assess the crossing.
- A number of pedestrians suggested the layout was quite confusing and so they were unsure of the directions cyclists and vehicles would be approaching the crossing from.

Analysis of the video data found that:

- On Arms 1, 2 and 3 nearly all cyclists and drivers gave way to pedestrians, while on Arm 4 on a quarter of cyclists gave way to pedestrians, reflecting the lack of zebra crossing on the cycle track.
- Car drivers were more likely to go in front of the cyclists crossing their path when entering the roundabout than when exiting it.

A.9 M28c Large vehicle Capacity Summary Findings Report

The M28 trials were concerned with understanding the capacity implications of using the Dutch-style roundabout design on UK roads. There were three sub-trials, namely M28a which investigated the fundamental vehicle capacity of the roundabout; M28b which investigated the effect of cyclists using the orbital cycle track on the vehicle capacity of the roundabout and M28c (this trial) which investigated the effect that long vehicles using the roundabout have on other vehicles using the roundabout. In this summary we are only reflecting the safety related findings of the M28c trial.

In this trial, several long vehicles (HGVs, buses, coaches and vans) used the roundabout while controlled cyclists circulated the orbital cycle path and cars followed the long vehicle round the roundabout. The trials were concerned with measuring the blocking effect long vehicles waiting to leave the roundabout had on circulating car traffic.

Long vehicle drivers were asked to comment on the use of the roundabout. In their comments, nearly all mentioned that seeing cyclists on the cycle track while on the exit arm of the roundabout was difficult as the cyclists were in the blind spot between their view out of the side window and the view in the rear-view mirror.