Cycle facilities and engineering: Summary of TRL research

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Executive Summary

This Summary Report describes the results of research into the performance of cycle facilities and engineering features. This work was carried out by TRL Limited on behalf of the UK's Department for Transport.

The project has been based on studies of several types of facility designed to assist cycle users, some of them innovative in the UK context. The studies that comprised this project were:

- Cycling in bus lanes (Reid S J and Guthrie N, 2004). TRL Report TRL610.
- An assessment of the cycle track in Royal College Street, Camden (Gray S, Gibbard A and Harper H, 2004). TRL Report TRL617
- Capacity implications of Advanced Stop Lines for cyclists (Wall G T, Davies D G and Crabtree M, 2003). TRL Report TRL585.
- Cycle track crossings of minor roads (Pedler A and Davies D G, 2000). TRL Report TRL462.
- Cyclists and 'continental' style roundabouts (Lawton B J, Webb, P J, Wall G T and Davies D, 2003). TRL Report TRL584.
- Cycling in vehicle restricted areas (Davies D G, Chinn L, Buckle G S and Reid S J, 2003). TRL Report TRL583.
- The effect of road narrowings on cyclists (Gibbard A, Reid S, Mitchell, J, Lawton, B, Brown, E and Harper H, 2004). TRL Report TRL621.

Each of these studies has been the subject of a dedicated report giving full details of the methodologies, results and conclusions reached. The purpose of this summary report is to present an overview of the project as a whole, with the objective of identifying generic features in the performance of facilities that may inform thinking in more general terms about the provision of cycle-friendly networks.

This report presents the background and key results from each of the studies. It features an overview chapter that considers the provision of facilities for cyclists from first principles and discusses the degree to which the facilities studied meet the necessary criteria of cycling facilities. The summary concludes with key recommendations for practitioners and policy makers to support them in ensuring that effective cycle facilities can be provided in the future.

1 Introduction

In the last ten years the importance of cycling, as a sustainable mode of transport, has come to be widely recognised. This recognition has resulted in commitments to increase levels of cycling being made in a number of key policy documents.

The National Cycling Strategy (NCS) was launched in July 1996 (DoT, 1996). It aimed to establish a culture favourable to the increased use of bicycles for all age groups, to develop sound policies and good practice, and to seek out effective and innovative means of fostering accessibility by cycle. It included targets to double the number of cycle trips between 1996 and 2002, and to double them again by 2012. In addition to setting a central target for the number of cycle trips, the Strategy encouraged local authorities and other groups to establish localised targets for increased cycle use.

The publication of the Government White Paper (1998) 'A new deal for transport – better for everyone' set out a vision of a more integrated and sustainable transport system in the UK. It introduced policies intended to make transport more sustainable, in which it was envisaged that cycling would play a key role. The White Paper endorsed and adopted the National Cycling Strategy targets.

The 10-Year Plan for Transport (DETR, 2000) 'Transport 2010' stated that 'Cycling accounted for less than 2% of all trips in 1998'. In light of this the plan included a target to treble the number of cycling trips from their 2000 level by 2010. 'Growth is expected to be triggered both by improved local provision for cycling, and from the impetus created by the National Cycle Network currently being set up ' (DETR, 2000).

As the 10-Year Plan recognised, an important strategy to support and encourage cycling is to provide viable local networks for cycle use. Accordingly, it has been necessary to carry out research into the best ways to provide such networks. This research project – Cycle Facilities and Engineering – has focussed on the particular facilities designed wholly or partly for use by cyclists in order to provide more information on how they function, leading to a better understanding of when, and how, they may best be deployed to achieve optimum outcomes.

The facilities investigated under this project were:

- Cycling in bus lanes (Reid S J and Guthrie N, 2004). TRL Report TRL610.
- An assessment of the cycle track in Royal College Street, Camden (Gray S, Gibbard A and Harper H, 2004). TRL Report TRL617
- Capacity implications of Advanced Stop Lines for cyclists (Wall G T, Davies D G and Crabtree M, 2003). TRL Report TRL585.
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The assessment of each of these facilities has been approached as a research topic in its own right and detailed research reports have been prepared describing the investigation and results of each. However, it was considered that there were important commonalities between the performance of these different facilities and it is proposed that more widely applicable principles and approaches should be drawn together from across the different projects to inform the development of a cycle-friendly infrastructure.

This overview report attempts to fulfil that function. It brings together a brief description of the main findings and recommendations of each of the research studies and seeks to draw out common threads. This exercise is potentially contentious since it requires a degree of extrapolation from different studies. Nevertheless, it is considered important in order to inform discussion on the role of cycle facilities and the most effective ways in which they can be used to support the policy objectives described above.

2 Research aims and objectives

The main aims and objectives of the research project commissioned by DfT on the design and engineering of cycling facilities can be summarised as follows:

- To gain a better understanding of cyclists' interactions with other users within cycling environments.
- To determine the attitudes and behaviour of cyclists and those other users coming into contact with cyclists.
- To identify situations where the cyclist might come into conflict with motorists or pedestrians – notably where cycle tracks cross side roads, in Vehicle Restricted Areas and at other junction layouts.
- To observe the behaviour of cyclists and other road users in response to the facilities provided.
- To determine the effect of 'cycle friendly' design in terms of cyclist and vehicle/pedestrian behaviour and the effects it has on the capacity for the aforementioned users.
- To provide practical options for increasing safety and convenience for cyclists without severe detriment to other users.
- To provide recommendations and suggestions for future design of cycle facilities.

These aims and objectives were intended to provide a better understanding of the cycling environment from all perspectives and in a variety of situations. As a result, it is hoped that practitioners will be better placed to accommodate the needs of cyclists.

3 Research methodologies

Although the methodologies applied within the individual pieces of research varied, similar techniques were used to obtain the necessary data for evaluation.

All of the research projects utilised the following research methodologies:

- Video camera surveys to identify certain behaviour or interactions between cyclists and other types of user.
- Questionnaire surveys of cyclists.
- Surveys of other users affected by cyclists' use of the facility. For example, bus drivers were questioned during the research on cycling in bus lanes, whilst vehicle drivers were surveyed as part of the analysis of cycle track crossings of minor roads.

In the research on Continental Style Roundabouts and Advanced Stop Lines the computer programs OSCADY and ARCADY were also used to predict the impact of design modifications to the cycle facilities. These programs, both created by TRL, are able to predict capacities, queue lengths and delays at junctions or roundabouts, and are constantly being updated through new research. The investigation of cycling in Vehicle Restricted Areas was the only study to utilise manual speed surveys and flow counts of pedestrians, in conjunction with the standard questionnaire and video surveys.

4 Research study summaries

This section provides a summary of the research projects conducted under the cycle facilities and engineering research programme. Each sub-section details the purpose of the study, the key issues, and the conclusions from it.

4.1 Cycling in bus lanes

This project considered the operational and safety aspects of the use of bus lanes by cyclists. The main aim of the project was to provide guidance on the practical options for increasing the safety and convenience of cyclists in bus priority schemes, and to obtain a better understanding of cyclist and bus interaction in bus lanes. It assessed the effect of cyclists on buses, and the physical interaction between the two modes in bus lanes according to a number of key parameters, specifically:

- The width of bus lanes.
- The provision of an advisory cycle lane.
- With-flow v. contra-flow bus lanes.

It also sought to elicit the views of cycle users and bus drivers on the use of bus lanes by cyclists.

A variety of techniques was used to collect the data for this project. These included static observation of interactions between buses and cycles; fixed video camera surveys of cyclists and buses sharing a bus lane; the use of bus enforcement cameras mounted on selected London buses to observe interactions; on-bus interaction surveys; interview surveys with cyclists, and a bus driver survey.

The project confirmed that bus lanes were popular with cyclists and could help to provide greater safety and journey time improvements for cyclists, whilst causing only minimal delay to buses. However, the project did highlight some important provisos. Firstly, it is necessary to note that contra-flow bus lanes were perceived to be the least safe for cyclists. Secondly, there was perceived conflict between bus drivers and cyclists. A substantial number of cyclists interviewed thought that bus drivers could be inconsiderate, whilst most bus drivers interviewed held a poor opinion of cyclists. Lastly, it appeared that wider lanes were better than narrower lanes for both cyclists and bus drivers, so long as they did not adversely affect cycling conditions in the oncoming traffic lane.

The recommendations which resulted from the research fell into four categories as follows:

Planning:

- The value of bus lanes to cyclists should be incorporated into appraisals of reallocating road space to buses.
- The use of bus lanes by cyclists should be anticipated and planned.
- Equality for cyclists using bus lanes should be encouraged by appropriate planning.
- Proposed changes to bus priority measures should be subject to Cycle Audit procedures.

Design:

- Bus lanes and other bus priority schemes should be designed for use by cyclists wherever this can be safely achieved.
- Where possible, bus lanes should be made wider (revised 4m 'standard') wherever cyclists are expected to use them.
- Where width permits (in bus lanes of 4m and over), advisory cycle lanes at the kerb-side of the bus lane should be provided inside bus lanes.
- Bus lanes should not deliberately be made narrow in order to prevent buses overtaking cyclists.
- Contra-flow bus lanes should be wider than the equivalent with-flow lane.
- Where bus lanes of less than 4m are provided, consideration should be given to upgrading drain gullies to kerb-face inlets.
- More research is necessary into the optimum methods of resolving conflicts and delays to cyclists at bus stops.

Maintenance:

- Bus lanes should be subject to more frequent inspection than the general highway network and should be prioritised for repair where damage is identified.

Education, information and enforcement:

- Efforts should be made to encourage bus drivers and cyclists to appreciate their mutual concerns.

- Bus lane regulations should be better enforced, particularly illegal parking and loading.
- The project revealed concerns about motorcycles using bus lanes, but further research into this is presently underway and therefore, no recommendations are made at this stage.
- Bus lanes should be shown on urban cycle route maps.

These recommendations, where appropriate, are drawn into the overview recommendations in Chapter 5, where consideration is particularly given to the issue of managing road space effectively to ensure that cycle routes are safe, coherent, direct, attractive and comfortable.

4.2 An assessment of the cycle track in Royal College Street, Camden

The Camden Royal College Street Cycle Track Scheme was completed in March 2000. It consisted of a 450-metre section of segregated two-way cycle track that linked with the wider London Cycle Network, and formed part of a strategic route connecting Kings Cross and Camden Town.

The main aim of the project was to determine the attitudes and behaviour of cyclists using the cycle track and those of motorists and bus passengers that traversed it. In particular, the research was intended to identify any conflict situations between cyclists and either vehicles or bus passengers. The methodology used to achieve this aim included behavioural video surveys overlooking a junction and a bus stop situated on the cycle track, and bus passenger, cyclist, driver and pedestrian interview surveys.

The pedestrians' perceptions of the Royal College Street cycle track were mixed overall, although a generally unfavourable impression pervaded. The main complaints that were made by pedestrians regarding the cycle track related to:

- Cyclist behaviour.
- Confusion, particularly arising from the two-way flow of the cycle track in relation to the one-way flow of the traffic.
- Potential conflict between users, particularly in the area where the cycle track merged with the footway.

Overall, the research concluded that the cycle track was well utilised. There was a belief among the cyclists using the track that it had improved safety, despite some problems with junction layouts where cycle movements came into conflict with vehicle movements. It was found that the installation of amber flashing lights (wig-wags) at problem junctions reminded drivers of the cycle track, and in particular, that it was two-way. There was little evidence of conflict between bus passengers and cyclists, although relatively few people used the bus stops along the cycle track route. However, cyclists believed the introduction of ramps to slow cyclists down on their approach to bus stops was a necessary precautionary measure.

Several operational problems concerning the cycle track were identified, including:

- Some vehicles appeared to ignore the stop line at certain junctions and consequently blocked, or partly blocked, the cycle track. The reason appeared to be the difficulty of obtaining a sufficiently clear view of the fast moving traffic from behind the cycle track to enable drivers to pull out into the traffic stream.
- Some vehicles also failed to give way to cyclists on the cycle track when turning at a junction.
- Some cyclists failed to recognise pedestrians' right of way at the bus stop.

This study resulted in few recommendations because the scheme was modified by the installation of speed tables at junctions during the course of the study, and TRL has not assessed the scheme in its revised form.

The issues arising from this project, specifically those concerning the legibility of cycle track crossings and the constraints they impose on other road users, are drawn together as part of a broader discussion of these issues in Chapter 5.

4.3 Capacity implications of advanced stop lines for cyclists

This project aimed to assess the junction capacity implications of installing Advanced Stop Lines (ASLs) for cyclists. ASLs are facilities that allow cyclists to position themselves ahead of queuing vehicles at signalised junctions and include a cycle approach lane to a waiting area between 4 metres and 5 metres deep (dimensions are defined in Traffic Signs Regulations and General Directions, 2002). It was considered that introducing ASLs might mean a loss of junction capacity for motorised vehicles, arising from three possible causes:

- Moving the drivers' stop line 5 metres further from the junction than its existing position.
- The reduced width or removal of a traffic lane to provide a cycle lane.
- The different queuing/positioning behaviour of cyclists.

The impact of such changes in junction design on capacity were investigated in this study, whilst consideration was also given to the behaviour of cyclists and vehicles at junctions with ASLs and cyclists' perceptions of these facilities.

The methodology used to carry out the research included the modelling of five different theoretical 'before' and 'after' scenarios using OSCADY; video surveys of four sites in Guildford 'before' and 'after' the installation of ASLs, and questionnaire surveys at three of the Guildford sites.

The project concluded that moving the drivers' stop line back 5 metres had no significant effect on inter-green times or on the capacity of flares, except where those were very short. It also determined that ASLs had no significant impact on junction capacity unless a traffic lane were removed in order to install them. The changes in capacity predicted by OSCADY were similar to those measured by the video surveys for lane 1 of junctions, indicating that the modelling program could be used effectively to assess the impact of introducing ASLs on a case by case basis (especially where a traffic lane was to be removed). However, it was noted that the OSCADY predictions were very different for lane 2 of junctions. Additionally, there

seemed to be no visible evidence that cyclist queuing/positioning behaviour had any noticeable effect on capacity, and it was noteworthy that newly installed ASLs appeared to meet with approval from cyclists. In light of these findings, certain recommendations were made including:

- Inter-green and minimum green times should be checked and possibly extended, particularly at large signal-controlled junctions, or where cyclists cross the stop line near the end of green.
- Consideration should be given to the positioning and extension times for vehicle detectors used in the control of traffic signals, although these were not specifically considered by the project.
- Signal controlled junction modelling computer programs, such as OSCADY, should be used to assess the impact of changes, especially where a traffic lane is to be removed.
- The compliance of motorised vehicle drivers with ASLs should be encouraged through the use of signs, road markings and education and/or enforcement.

The research confirmed that reallocating space to cyclists at junctions could increase cyclists' perceived utility with minimal impact on capacity for other road users (with certain provisos). Such restructuring of space at junctions for the benefit of cyclists is discussed further in Chapter 5, where it is considered in reference to the need to reduce speed and volume of other users. Furthermore, the issue of enforcement to ensure success of such space reallocations is also put into context.

4.4 Cycle track crossings of minor roads

The purpose of this study was to assess a variety of cycle track crossing arrangements, most of which included priority for cyclists. Situations where cyclists appeared to come into conflict with motorists or pedestrians were identified, and the severity of these interactions evaluated in order to put forward recommendations regarding the design of cycle track crossings. The research also sought the views of cyclists concerning the safety and convenience of the cycle track crossings.

Five survey sites with different design qualities were chosen for video and interview surveys. The results of each video survey were analysed to obtain the numbers of cyclists and motor vehicles on the major road passing a junction with a minor road, and the vehicles entering or exiting this minor road. The types of manoeuvre were recorded and the interactions between cyclists using the cycle track crossing and motor vehicles were noted. The interview survey aimed to discover the views of cyclists on the safety and convenience of the cycle track crossings, including those cyclists who chose to continue cycling on the major road rather than the cycle track.

The project uncovered several important findings including:

- The majority of observed interactions which concerned cyclists were non-hazardous.
- Cycle tracks with priority for cyclists across minor roads appeared to work satisfactorily in some circumstances, but by no means all.
- High flows of motor vehicles crossing the cycle track led to higher rates of interaction per cyclist, and possibly conflict.
- High flows of cyclists increased the likelihood of drivers giving way to cyclists and being alert to cyclists on the crossings.
- Crossings where cyclists had no priority caused the least confusion. However, that did not mean that they were necessarily the correct design in all cases.
- Straight-across cycle track crossings (not bent out) were likely to be obstructed by vehicles leaving the minor road, particularly where drivers had restricted visibility of the major road, or where flows on the major road were high (and gaps few).
- The sites that appeared to cause most confusion or where the priorities were most misunderstood, were crossings with partial priority for both cyclists and motor vehicles.
- Some cyclists continued to use the major road carriageway in preference to the cycle track.
- There were fewer problems at sites where the cycle track was bent out from the junction. Problems, if any, were likely to arise from vehicles turning off the major road into the minor road. Vehicles turning left had the least time to respond to cyclists who were travelling on the cycle track in the same direction. Good visibility was needed in those situations.
- Visibility to the right from the minor road was very important. The 'Y' distances of 30-45 metres (based on a 'X' distance 2.4 metres behind the first give way line) did not allow drivers to get an adequate view to the right (of the road or cycle track), given the traffic flows on the major road at the sites in Oxford. As a result, vehicles blocked the straight-across cycle crossings.

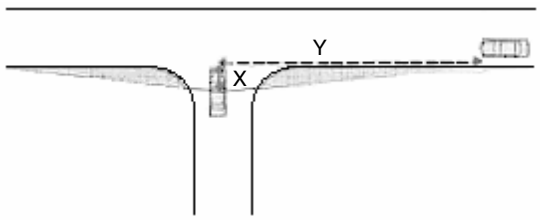

Figure 1 Visibility from the minor road to the major road (Department of Transport & Department of the Environment, 1992. Design Bulletin 32)

- Visibility along the cycle track was more restricted than along the carriageway, especially when the cycle track was away from the kerb, behind the footway.
- Humped cycle track crossings seemed to be effective in slowing drivers and indicating the presence of a cycle crossing to drivers.

- The humped crossings also appeared to reinforce the traffic signs and markings indicating to drivers that the cyclists had priority. However, the hump did not prevent drivers from obstructing crossings that were not bent out, where drivers had restricted visibility of the major road.
- Humped cycle track crossings were preferable where cyclists had priority.
- If humps are not bent out from the major road, the height and gradient should not look severe or motor vehicles might stop on them to enable acceleration from the minor road onto the major road, so obstructing the path of the cyclist.
- Humped cycle track crossings appeared advisable on bent cycle track crossings because they encouraged motor vehicles to slow when entering and exiting the minor road.
- It might be advantageous for cycle track crossings to be coloured across the minor road and also for some 10 metres either side to increase driver awareness of the cycle track.
- Attention to detail was found to be important. Relatively 'minor' features such as the location of the street furniture and excessive vegetation appeared to affect the safety at several sites.
- Pedestrians usually chose to cross on the cycle track crossings. The set-back 'Give Way' lines, humps and surface colour made crossing easier.
- Consideration should be given to pedestrian space. Sandwiching pedestrians between the road and the cycle track encouraged pedestrians to walk on the cycle track and might result in cyclists cycling directly in front of gateways and openings.

Certain design recommendations were outlined as a result of the research. Firstly, it was advised that when contemplating whether to provide a cycle track, designers should fully consider the design and safety implications of crossing a minor road. The risks to cyclists on cycle tracks, including the crossings of minor roads, must be weighed against the risks to cyclists who use the major road, with the safer option depending on a variety of site-specific factors. It was concluded that if satisfactory crossings of minor roads cannot be provided, a cycle track may not be a sensible option. Consequently, regardless of the design of the cycle track crossing, consideration should first be given to improving conditions for cyclists on the main carriageway, in accordance with the hierarchy of measures, recommended in Cycle Friendly Infrastructure (IHT *et al.,* 1996).

Secondly, the designer needs to consider a range of factors when deciding whether a satisfactory cycle track crossing can be provided and, if so, how it should be designed. The most important factors appear to be:

- Flows of vehicles into and out of the minor road (i.e. crossing the cycle track).
- Visibility from the minor road to the major road, particularly to the right.
- Traffic flows and speeds on the major road, and gaps in the flow.
- Availability of land on which to bend out the cycle track crossing.

Thirdly, giving cyclists priority on straight across crossings is not recommended when:

1 Visibility splays are sub-standard for the class of road and 85th percentile vehicle speed.
2 Where traffic flows on the major road are above 500 vehicles per hour and visibility from the minor road is inadequate for vehicles.

Lastly, the research suggested that clear markings and signing were needed to clarify whether cyclists or drivers should give way, and that cycle tracks which give cyclists priority should be humped, clearly marked and bent out from the carriageway wherever possible.

This report discusses many of these issues in greater detail in Chapter 5, including the legibility and ownership of space related to the site characteristics of cycle facilities, and the constraints they place on all users.

4.5 Cyclists at continental style roundabouts - report on four trial sites

This project investigated the effect of 'continental' roundabout geometry on the safety of cyclists at four pilot roundabouts. The main aim was to investigate the safety of cyclists at these roundabouts in order to produce guidelines to improve the cycle friendliness of roundabouts.

Four roundabouts located in Woking, Nottingham (two sites) and Gloucester were re-configured to a continental style, which was investigated. These roundabouts were altered towards a representation of the continental type of roundabout, but were not quite accurately configured to a continental style. The research involved 'before' and 'after' video surveys of user flows, turning proportions and manoeuvres; an attitude survey of cyclists, which focussed on conflict points; modelling of the roundabout flows using ARCADY, and an analysis of accident statistics at the roundabouts before and after installation.

The research found that it was only appropriate to make these 'continental' design changes to roundabouts with lower flows where only one lane was required because none of the design changes, as implemented, had a significant effect when the flows were too great. In fact, it was confirmed that cyclists felt much safer when there were lower traffic flows on roundabouts, irrespective of the modifications to their design. Nevertheless, the introduction of cycle lanes and crossings, and the reduction to a single lane of traffic where possible, appeared to increase the perception of safety because of the general popularity among cyclists of measures to slow motor vehicles and discourage them from squeezing cyclists against the kerb. However, the examination of accident statistics could not produce any firm conclusions as to whether or not the roundabouts were safer because the statistical records since the modifications were too short.

Although none of the features introduced could definitively be said to improve the safety of cyclists, the following features did appear to have a positive effect on the safety of cyclists:

- A tighter geometry on approaches, whereby vehicles approach the roundabout radially, makes it more likely that cyclists will be in a driver's field of vision.
- A reduction to one entry and exit lane on each arm appears to make it easier for cyclists to turn right.
- An enlarged central island to reduce the circulating carriageway to one lane appears to make circulation easier for cyclists.
- Introducing toucan crossings on the arms of roundabouts makes it easier for less experienced cyclists to cross the arms of a roundabout safely.
- The addition of cycle strips adjacent to each of the give-way lines at the entries to roundabouts appears to deter motor vehicles from overshooting onto the roundabout.

It was very clear from the research that there was a need to promote understanding of continental style roundabout layouts. For example, at the Nottingham roundabouts substantial numbers of cyclists did not understand how to use the continental roundabouts to increase their safety (e.g. by cycling in the centre of the carriageway). It was also indicated that other road users might need to be taught how to use them because they were not laid out in the conventional way for the UK. Specifically, car drivers must be made more aware of cyclists and be discouraged from edging over the give-way markings.

Most importantly, this project identified the need for thorough further research when innovative measures are introduced. The continental-style roundabouts were believed to have a positive effect on safety. However, the research highlighted that such measures should be thoroughly assessed before being advocated as good practice. This seems particularly the case where the measures aim to solve specific problems, rather than just to provide an advantage to cyclists, which is an issue that is discussed further in Chapter 5.

4.6 Cycling in Vehicle Restricted Areas

This study was intended to provide a better understanding of cyclist and pedestrian behaviour in Vehicle Restricted Areas (VRAs). It involved a survey of cycling behaviour in sites in Cambridge, Hull and Salisbury where cycling was prohibited for part or all of the day. VRAs are those areas of the highway where access for vehicles is heavily restricted, usually to provide a more comfortable environment for pedestrians, and where cyclists are often prohibited on the grounds of pedestrian comfort and safety. The study also aimed to provide practical guidance on the options available for increasing the safety and convenience for cyclists without detriment to other users. It did not address the general question of whether cyclists should be permitted to use VRAs.

Data were collected to test the hypothesis that cyclists slow down and get off when pedestrian flow increases, and to investigate the relationship between perceived and actual behaviour of the user groups. The methodology included video monitoring, manual speed surveys, flow counts of both pedestrians and cyclists between the hours of 0800 and 1800, and interviews with 300 pedestrians and 150 cyclists. Further data were presented concerning cycling speeds and dismounting. From the range of qualitative and quantitative data collated, it was possible to ascertain the types of cyclist that were most likely to ignore bans or to cycle fast.

The observation surveys showed that the majority of cyclists in VRAs modified their behaviour by slowing down or dismounting as pedestrian numbers increased. However, a significant minority (mostly young males) rode fast in VRAs, even at pedestrian peak periods. Cyclists appeared more likely to dismount or slow down where there was a cycling ban, when pedestrian flows were high, when cyclist flows were low and where the percentage of young male cyclists was low. Other local factors also influenced cyclist behaviour.

The pedestrian attitude surveys showed that the majority of pedestrians were not particularly concerned about cyclists in the pedestrian area. Before prompting, more pedestrians spontaneously cited litter to be a significant problem than the number who expressed concerns about sharing space with cyclists. Most pedestrians accepted sharing with cyclists in VRAs. However, in two of the three survey cities, a majority of pedestrians was in favour of banning cyclists for at least part of the day. Pedestrians' concerns about cyclists were greater when the flow of cyclists was higher. A small, but not inconsiderable, number of pedestrians also reported having seen, or been involved in, an incident with a cyclist in a VRA. Some of those incidents apparently involved injury, which suggested that STATS19 road accident reports might not provide a comprehensive indication of pedestrian safety in VRAs.

Although most pedestrians and cyclists understood the meaning of traffic signs used to indicate the permitted users and prohibited traffic in VRAs, a substantial minority did not. Improvements in public understanding might be achievable through appropriate publicity and education.

The study concluded that expecting pedestrians and cyclists to share those areas was not an ideal solution because most pedestrians would probably prefer not to have cyclists using VRAs at busy times, and no doubt many cyclists would prefer not to have to negotiate pedestrians. However, as with many planning and traffic problems, a compromise might be the most practical way of marrying sustainable transport objectives with public inclinations. The surveys indicated broad agreement among the public that some attempt at segregation of pedestrians and cyclists within VRAs would be desirable.

Taking account of the results of a wider survey of sites, those VRAs permitting cycling that seemed to work most satisfactorily showed the following characteristics:

- Wide spaces
- Clear signs
- Street furniture channelling cyclists towards the centre of the street, away from doorways
- Footway and carriageway areas still defined to some extent.

The report recommended that local authorities considering these issues might find it helpful to undertake observation surveys similar to those carried out for this

VRAs study because the survey costs would not be especially onerous, and objective data on the behaviour of cyclists in regional situations would help to inform local debate. Chapter 5 discusses the issues raised by this study in a broader context, specifically considering the need for legibility within VRAs to reduce conflict and the negative consequences of allowing use by cyclists.

4.7 Cyclists at road narrowings

This study considered the effect of road narrowings on cyclists and the effectiveness of measures to prevent conflict between cyclists and motor vehicles where widths were constrained by a variety of features, most typically, kerbside parking and central islands in the carriageway.

The research methods used included:

- Consultation with eleven organisations representing cyclists, pedestrians and drivers.
- An on-line questionnaire survey of cycle users.
- Video monitoring of sites in Clitheroe, Woodmansey, Solihull, Langho and Lytham St Anne's.
- The development of virtual reality simulations of roads with combinations of central refuges and cycle lanes, through which subjects 'drove', whilst their attitudinal and behavioural responses were recorded by completing questionnaires and virtual reality equipment, respectively.

The consultation exercise established that many individuals perceived road narrowings as a serious safety issue for cyclists, and as such, constituted major 'obstructions' on vital cycle routes. In particular, the majority of the interviewees questioned the decision of authorities to install such features deliberately as a form of traffic calming. This was because the installation of such features was rarely perceived as having resulted in any significant level of calming, yet was perceived to have made cycling in these locations uncomfortable, intimidating and potentially more dangerous.

The questionnaire survey found that a large majority of respondents stated that narrowings caused them difficulties while cycling and that this was most prevalent among female cyclists. However, generally the questionnaire results suggested that road narrowings were not sufficiently threatening to force cyclists to utilise the footway, or choose alternative routes for their journeys, though they remained a cause of anxiety. Narrowings deliberately introduced by refuges and central islands were considered most problematic and it was determined that the mechanism which caused stress was related to the proximity of vehicles and their intrusion into cyclists' space.

Respondents reported that stress could be exacerbated by the presence of certain types of vehicle, notably light and heavy goods vehicles. Moreover, the behaviour of drivers could further increase the intimidation that cyclists claimed to suffer at road narrowings, with attempts by drivers to overtake level with the narrowing and high motor vehicle speeds being the most common sources of concern. A large number of the respondents indicated that they sometimes modified their behaviour by pulling over when approaching narrowings, although the majority did not. Nevertheless, narrowings were stated to be less stressful overall than large roundabouts.

The video monitoring of narrowing sites was hampered by the difficulty in recording statistically significant numbers of encounters between drivers and cyclists from which to draw conclusions. Nevertheless, some tentative results were identified:

- The presence of a cycle lane appeared to encourage cyclists to position themselves nearer to the kerb when being overtaken near a road narrowing.
- The presence of a mandatory cycle lane, but no cycle slip, appeared to encourage drivers to position their vehicles nearer cyclists than if there were no cycle lane, although there was no direct indication in this work that it made cycling more dangerous.
- The introduction of warning signs at Woodmansey appeared to encourage drivers to overtake the cyclist before the island, and to leave less space when overtaking, though when the surface of the cycle lane was changed from grey to green, drivers became more likely to wait until after the island before overtaking.
- Whilst the presence of speed humps next to the road island slowed traffic, no conclusion could be reached as to whether that affected drivers' decisions as to where to overtake cyclists in relation to the island.
- In built-up areas, where traffic was heavier and vehicles sometimes parked on the edge of the road, cyclists travelled further from the kerb, and drivers were less likely to overtake.

Some broad patterns also emerged from the virtual reality testing. The speeds at which people travelled seemed to be affected by the presence of a road island. Even where drivers decided to overtake before the island, they appeared to slow down on the approach to the island, purely because of its presence. There was also an indication that roughly two-thirds of drivers would make the same decision, irrespective of the presence or otherwise of a cycle lane. With the remaining third, it appeared that the presence of a red cycle lane, as opposed to a grey one, or no cycle lane at all, encouraged drivers to overtake the cyclist before the island. However, none of the participants indicated that this was a cue in the questionnaires, so that supposition may be incorrect, or it may have been that there was a sub-conscious cue of which drivers were not aware.

In the situation examined by the virtual reality experiment, it appeared that young males were far more inclined to overtake the cyclist before the island than any other group. In general, men seemed more likely to overtake before the island than women. Those who claimed that they slowed down when overtaking seemed less likely to overtake before an island. However, for those people, perhaps the decision-making point, or area, was ahead of the position created in this experiment.

The research recommended that existing DfT guidance suggesting a minimum narrowing width of 4m should be more closely observed. It was recommended that where cycle lanes were used in road narrowings to

reserve space for cyclists they should be given coloured surface treatment in order to increase their effectiveness, and possibly to reinforce the traffic calming effect of the scheme. It was also recommended that where lanes were introduced they should be 2m in width. If space only permitted the provision of significantly substandard width cycle lanes, it was suggested that other traffic calming measures, particularly vertical features, should be used to reduce the speed of traffic approaching narrowings.

Finally it was concluded that, given the equivocal effect of different measures to reduce the impact of road narrowings on cyclists, a rigorous assessment should be made, on a case by case basis, of whether narrowings should be deliberately introduced before these features are implemented. In particular, it was suggested that the positive gains to other users should clearly offset the detrimental effect of these features on cycle users.

Chapter 5 deliberates the matters raised by this study in a wider context, particularly focusing on the need for highway engineers to be aware of the requirements of cyclists so that road space is effectively managed for all users.

5 Overview discussion

The Cycle Facilities and Engineering research project sought to monitor and evaluate the effectiveness of facilities designed wholly or partly to improve the accessibility of the transport network to cyclists. The common theme linking several of the facilities studied was one of innovation in the UK context. The project provided an opportunity to assess the performance of these facilities in order to support recommendations to improve their operation where necessary.

The summaries of the research into the performance of individual facility types have been provided in the preceding chapters. However, this overview discussion attempts to identify common threads that may be applicable, not just in the particular contexts of the specific facilities examined, but in informing general thinking on how best to provide networks fit for cycling.

5.1 Role of cycling facilities

In considering this topic, it is helpful to begin by reiterating the necessary characteristics of cycle route networks. These are based around the requirements of cyclists as end users and are commonly characterised as:

- Coherence.
- Directness.
- Attractiveness.
- Safety.
- Comfort.

(CROW, 1993; IHT, 1996).

A successful cycle route network will need to offer users the optimum combination of the above. It is important to recognise that all of these characteristics are important to users, but that some may be considered quantitative and others are qualitative in nature. This is significant in that a tendency to overlook or ignore those aspects that are difficult to evaluate objectively, such as attractiveness or comfort, may render networks unacceptable to users, despite their performance in relation to more measurable parameters such as safety.

In many contexts, the general highway and rights of way network may effectively provide cycle users with routes that satisfy all of the requirements described above. Arguably then, cycle-specific facilities can have two meaningful functions:

i To extend the potential access to the highway network from the cycle facilities provided.

ii To improve the performance of the network from the cycle user's perspective. All of the facilities studied fall into this category.

The deployment of specific facilities may assist the achievement of these objectives in two ways:

a By positively advantaging cycle users over some or all other classes of road user, thus making cycling relatively more attractive. Examples of such facilities include access to bus lanes and bus priority facilities, or through areas that are otherwise restricted for vehicles and cycle-only links that provide more direct routes, such as across parks.

b By overcoming problems in a particular location for cycle users that may reduce their experience of any of the five necessary characteristics described above. Examples of this approach include bypasses to road narrowings, signing to overcome deficiencies in information and 'continental' roundabout geometries that can address problems caused by highway features.

The facilities studied as part of this research project may be broadly classified into this scheme as follows:

Positive advantage	Problem solving
Cycling in bus lanes	
Cycle advanced stop lines	Continental style roundabouts
Cycle track crossings of side road junctions	Cycle measures at road narrowings
Royal College Street cycle track	
Cycling in Vehicle Restricted Areas	

Clearly, this distinction is not absolute. Some facilities may contribute in both ways; thus cycle advanced stop lines accord priority whilst also permitting a safer road positioning for cyclists. Similarly admittance to vehicle restricted areas advantages cyclists by providing direct routes whilst simultaneously overcoming the difficulties that can be entailed in circumventing a VRA. Nevertheless, these two possible outcomes provide the basis of a framework for considering the performance of cycle facilities, i.e. do they effectively provide priority, or contribute to an overall network that fulfils cycle-users' requirements, and if so, to what extent?

5.2 Operation of cycle facilities

Most cycle facilities, including some of those studied, are directly or indirectly intended to manage the relationship between cyclists and other classes of user. Where difficulties arise for cycle users in relation to other users they typically consist of one or more of three elements that may affect cyclists singly, or in combination with one another:

1 *Volume and nature of other users:* High volumes of other users may interfere with the free movement of cyclists, particularly where they are making conflicting manoeuvres. This may be unavoidable in some situations and represent general congestion. At the extreme this even applies to other cycle users. Moreover, certain vehicle types are considered particularly intimidating to cycle users, HGVs for example, and sharing space with these may be a source of stress and hazard to cycle users.

2 *Speed differential between cycle users and others:* A significant speed differential between cyclists and other users is often considered one of the most significant components of perception of danger on the part of cycle users.

3 *Proximity of other users:* Where space is shared with other users, a close proximity between cyclists and others, particularly motorised vehicles, may reduce cyclists' sense of safety and comfort. It is suggested that there is a relationship between speed differential and the degree of proximity acceptable to cycle users.

Thus, where the general highway network does not offer cycle users adequate conditions, highway and traffic management features, including cycle facilities, may be deployed to reduce some, or all of the above. The mechanism that underpins all of the cycle facilities studied is their function as a means of enabling or controlling physical relationships in space between cycle users and others, thus, primarily, attempting to reduce proximity. This control may be attempted in a number of ways, ranging from regulatory and perceptual methods, through physical elements of control, through to absolute physical constraint (e.g. segregated facilities with physical barriers).

Different techniques to control spatial relationships may be said to occupy places in a hierarchy (Diagram B) of interventions from complete physical integration, in conditions of unsegregated shared use with pedestrians, or with vehicles, through to complete segregation. The desirability of a given level of segregation in this hierarchy will vary according to the outcome in terms of cycle users' requirements as well as considerations such as the ratio of costs to benefits and the effect on other road users. The increasing degree of physical segregation also broadly reflects a correspondingly increasing degree of intervention, and probably investment, on the part of the highway authority.

The hierarchy may also be said in some ways to reflect a declining desirability from full integration through to full segregation, as recommended by the IHT in its Cycle Friendly Infrastructure guidelines (IHT, 1996) that received the endorsement of the Department for Transport. In the guidelines, a hierarchy of solutions for cyclists was proposed. It was recommended by IHT that consideration of measures should be from traffic reduction through traffic restraint, reallocation of road space and segregated cycle facilities, in that order of preference, with each stage needing to be established as not viable or applicable in the context prior to moving on to the next. The 'hierarchy of solutions' approach is not dogmatic: it represents a pragmatic approach to the problems that are frequently encountered in attempting to provide routes that meet user needs in parallel to the highway. This particularly relates to urban areas, where increases in vehicular safety may be undermined by reductions in cohesion, directness or personal safety and give rise to conflicts where networks intersect (as evinced by the studies at Royal College Street and of cycle track crossings of side road junctions). Furthermore, it may be noted that as the designer progresses along the hierarchy, the emphasis gradually shifts from attempting to influence the spatial behaviour of other user types to attempting to influence the behaviour of cycle users. It could be argued that a broad indicator of success in the provision of a facility may be the degree to which it facilitates the normal behaviour of the cycle user in the context, as if there were no other users present.

The merit of such control over spatial relationships exists in the extent to which it provides the necessary characteristics of a cycle route. Practically, however, it may also have other effects, including disrupting traffic flow and reducing road or junction capacity. The degree to which designers are able to balance competing demands is partly a matter of context, but also involves political commitment and a deliberate fulfilment of broader policy objectives. In terms of the functionality of cycle facilities, however, it is evident that as well as types of facility there may be said to be 'degrees' of facility relative to the extent to which they fulfil their objectives. This requires consideration not just of the existence and intended purpose of the ideal facility, but of its actual outcomes in a specific context; hence the quality of provision is significant, as is the way in which users interpret and respond to the facility (see Figure 2).

5.3 Degree to which facilities studied have been successful

In considering how the facilities studied in Cycle Facilities and Engineering have performed in terms of the hierarchy of interventions, the following overarching criterion may be applied: do they successfully provide priority or improve network performance?

This, in turn, may be broken down into the following questions:

i Do they contribute to a more direct, safe, coherent, comfortable and attractive cycle route?

ii Do they undermine any of the above?

iii Do they constrain the cycle user or other users?

iv Do they have significant negative consequences for other road users?

Each of these questions is addressed below in relation to the facilities studied:

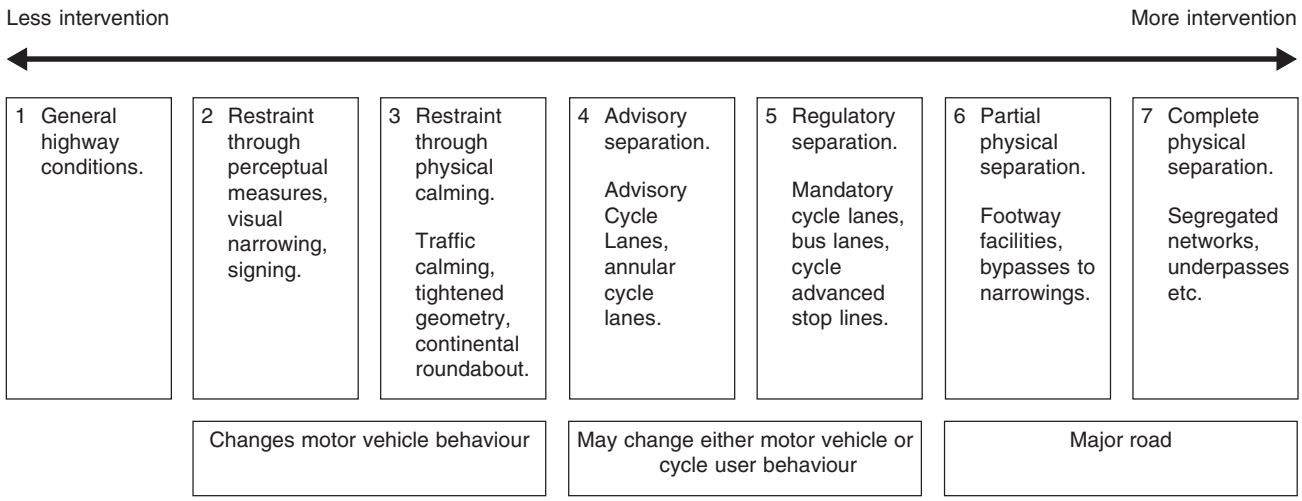

Figure 2 Hierarchy of interventions

i Do they contribute to a more direct, safe, coherent, comfortable and attractive cycle route?

The performance of the cycle facilities in this respect was clearly variable. Bus lanes were found to be effective measures that were popular with cycle users. The Royal College Street Cycle track, similarly, could be considered successful both in terms of the degree of use attracted by the facility and the positive views of users, despite some evidence of continuing conflict at junctions.

The advanced stop lines were found to be successful as cycling facilities and were popular with users, although there was evidence of misuse by a significant number of drivers. Admittance to Vehicle Restricted Areas was successful from the perspective of cycle users and, to a degree, appeared to be self-regulating.

Less unequivocally successful were attempts to redesign roundabouts to reflect continental geometries. These were found to vary in their performance and in cyclists' attitudes towards them. The significant variable that appeared to affect their performance was their ability to reduce traffic speeds and the flows of traffic through them. This suggests that, while the principle is sound, it requires careful application in order to provide genuine improvements for cycle users. At the extreme, this measure may in fact worsen conditions for cyclists if proximity to motor traffic is increased while flows and speeds of motorised traffic remain at levels sufficient to intimidate cyclists. Certainly this was perceived to be the case by cyclists surveyed at one of the sites, although long-term casualty information was not available to assess the accuracy of users' responses. Here, more research needs to be carried out on other trial roundabouts in order to obtain a better understanding of the degree of effectiveness in reducing potential conflict, increasing safety and engaging users' compliance with the schemes' 'rules'.

As with the roundabouts, the measures deployed to mitigate the effects of road narrowings seemed variable in their success. The most successful measures at road narrowings appeared to be those that reduced vehicle speed and enforced a reduced proximity through physical barriers. The least successful were those that advised drivers to concede priority to cyclists, although it is significant that all of the narrowings studied were substandard relative to DfT guidance. Similarly equivocal were attempts to continue cycle tracks across side road crossings. These were found to work in certain circumstances, but to be capable of inducing confusion among users, and in some cases were ignored by motorists seeking to secure sightlines at the junctions. These disadvantages may be 'designed out' through provision of humped crossings and 'jug handle' alignments, although these require a significant amount of land. The interesting aspect of motorists' responses was that they indicated the limitation of schemes that rely on user compliance with the scheme's advice. It might be inferred that where the scheme was considered by motorists to compromise their safety, or possibly convenience, it was largely ignored, although it is impossible to say whether it induced greater alertness and care among users. Cycle users demonstrated a similar response in relation to restrictions on their use of vehicle restricted areas. In the absence of any direct police enforcement, all of the schemes studied, and all schemes based on advisory interventions, are dependent on the compliance of users and this may be variable depending on the interpretation of users as to the costs of compliance to themselves.

Overall, the research has shown that the degree of effectiveness can be site-specific, particularly where effectiveness is dependent on un-enforced compliance.

In basing an assessment of facilities around outcomes, it must be remembered that behaviours observed at facilities may not necessarily reflect solely the design of the facility. In particular, the behaviour resulting from the introduction of a highway feature is also influenced by road users' understanding of the purpose of the facility.

Recent research by TRL into driver attitudes and psychology in relation to cyclists has revealed a widespread lack of understanding among road users of some relatively common facility types. Evidence from a questionnaire survey among drivers in five UK towns found that there were significant variations in drivers' familiarity with different types of cycle facility, as indicated in Table 1.

Table 1 Survey respondents' familiarity with cycle facilities

	Advanced stop lines	*Cycle lane*
Number of respondents	620	620
	%	%
Yes – noticed facility	74	92
No – not seen facility	26	6
Not sure	1	1

Source: Basford et al., 2001.

N.B. Percentages of respondents to the nearest 1% (rounding errors mean totals are not always 100%).

ii Do they undermine any of the above?

As noted above, there are certain circumstances in which some of the facilities might fail to deliver improvements and might, in fact, worsen conditions. The two instances where this is most marked are where continental roundabout geometries are adopted in circumstances where vehicle flows remain above 5000 per day, or fail to reduce vehicle speeds sufficiently. The second is more equivocal and concerns the unpredicted effects of introducing signing and cycle lanes at road narrowing sites. Caution must be exercised in expressing this reservation, since the number of interactions captured by the study were relatively low. Nevertheless, the narrowings study found that the main effect of introducing the signing was that more motorists attempted to overtake cycle users on the approach to the narrowing. This might have reflected the specific wording and location of the signs, but nevertheless suggested that caution should be exercised in adopting this strategy. Similarly, cycle lanes appeared to result in an increased tendency among drivers to pass closer to cyclists. This contrasted with the intended effect, but nevertheless it was consistent with that tentatively identified by recent work on the psychology of drivers' responses to cyclists (Basford *et al.*, 2002) and might result from giving drivers confidence as a result of defining 'ownership' of space more clearly and therefore discouraging cautious behaviour. That this should be so suggests that, in wider terms, the provision of a 'cycle facility' should not be considered a self-evidently positive step since, beyond its value in communicating the possible presence of cyclists to drivers, its actual outcomes may not be those anticipated and hence the effects on cycle users may be negative. This is likely to be particularly the case where sub-standard facilities are provided that encourage less separation, and a closer proximity, between cycle users and other road users.

iii Do they constrain the cycle user or other users?

The facilities studied all, literally, attempt to facilitate cycle use. Nevertheless the provision of cycle tracks that do not afford cyclists priority over side road crossings require the cycle user to concede priority to vehicles entering, or emerging from, side road junctions in a way that would not be expected of cyclists using the highway. It was also notable that cycle users exercised a degree of self-regulation in using some of the facilities: when approaching side road junctions, some claimed to increase their vigilance, even if technically they had priority, lacking confidence in the willingness of drivers to give way. Similarly, in the vehicle restricted areas, cyclists generally seemed to modify their behaviour voluntarily, slowing down, and many ultimately dismounting, as pedestrian density increased. Interestingly, this self regulation seems to be divorced from the actual regulation of the vehicle restricted area; many cyclists were apparently more confident in their own judgement of the safety of conditions than of the legal requirements, with 60% of cyclists continuing to ride despite prohibitions but with many nevertheless showing a willingness to react to changes in pedestrian flow.

iv Do they have significant negative consequences for other road users?

The only general measurable negative effects on other road users resulting from the facilities studied were in terms of stated preference. Thus the survey of bus drivers found a reluctance, in principle, to share space with other road users, although cyclists, while disliked, were considered a less serious nuisance than cars. Similarly, car drivers were less satisfied than cyclists with the performance of the Royal College Street cycle track. In principle, all of the facilities on the highway that seek to reallocate space from motorised traffic to cyclists might be said to have a negative effect on motor vehicle users to the extent that they are successful. Interestingly however, where this might be expected to be most significant, at junctions, the project found that the provision of an advanced stop line did not reduce junction capacity, provided that the number of vehicle lanes in the junction was not reduced.

Where admittance of cyclists to vehicle restricted areas is concerned, there is evidence from other studies that indicates that, while this is generally successful from the perspectives of most users, for some vulnerable classes of pedestrian, the use of VRAs by cyclists is claimed to have significant negative consequences in terms of anxiety and fear (Beuret *et al.*, 2000). Conversely, other studies have concluded that there is little evidence of conflict in actual encounters between cyclists and pedestrians (Uzzell *et al.*, 2000). The evidence from this project was that the majority of users supported the idea of cyclists being able to use the VRA, but there was also widespread support for them to be excluded at certain times and for their paths to be better delineated. The study also found that many cyclists were willing to regulate their own behaviour, presumably in response to their own assessment of risk. Nevertheless, a minority of cyclists, predominantly younger males, did not seem so responsive to conditions. While it may be possible to mitigate the consequence of this behaviour by design, careful consideration should be given to the way in which some cycle users may behave in a VRA and the use of enforcement measures should be considered where necessary.

The overall performance of the facilities studied is summarised in Table 2.

Table 2 Overall performance of facilities

Facility studied	*Contribution to more successful routes*	*Negative consequences for cyclists*	*Whose behaviour is actually modified*	*Are there negative consequences for others*
Bus lanes	Yes – improve safety and access to priority features.	No	General road users. Buses	No – there is no evidence of significant delays to buses.
Cycle advanced stop lines	Yes	No	General road users	No, provided a general purpose lane is not removed.
Vehicle restricted areas	Yes	No	Cycle users	A minority of cycle users fail to modify their behaviour, potentially leading to intimidation of vulnerable pedestrians.
Features at road narrowings	Variable	Yes	Varies	No
Cycle track crossings of side road junctions	Variable	Sometimes	Varies	Sometimes.
Royal College Street cycle track	Yes	No	Varies	Some conflict with vehicles at side-road junctions.
Continental style roundabouts	Variable	Sometimes	Varies	None recorded.

5.3.1 Legibility and education

The individual studies showed that the legibility of cycle facilities was a recurring issue, mainly as they identified instances where cyclists appeared to have a poor understanding of how a particular cycle facility should be used. For example, poor legibility was clearly referred to in the report on 'Cyclists at Continental Style Roundabouts'. That report suggested that the modifications in the design of the Nottingham roundabout actually seemed to discourage cyclists from using that facility. It was suggested that this was the result of cyclists failing to comprehend the new 'continental' layout.

The individual reports also indicated that the legibility of cycle facilities concerned other road users too, in particular, vehicle drivers. For example, the report on ASLs indicated that maintaining the visibility of road markings and introducing new signs could help to encourage the compliance of motorised vehicle drivers with ASLs, which many drivers currently ignore.

The reports on VRAs and cycle track crossings similarly indicated that some physical definition between the footway/crossing and the normal carriageway is preferable if cyclists are allowed entry or have priority, as it raises awareness and reduces the potential for conflict.

It must be noted that it is sometimes difficult to distinguish whether the incorrect use of a cycle facility is due to its poor legibility or other design qualities, which impair its proper use. For example, the report on cycle track crossings of minor roads indicated that 7% of cyclists in Oxford used the major road carriageway in preference to the cycle track. The major reason for this was that vehicles, as a result of a limited visibility splay and heavy traffic along the major road, frequently obstructed the track and consequently, they obstructed cyclists' journeys. The problem was not due to the poor legibility of the cycle facility. Nevertheless, a large proportion of the conflict observed occurred as a result of lack of awareness amongst user groups over space and priority. This occurred in virtually all types of scenario investigated in the Cycle Facilities and Engineering research reports.

The issue of cyclists using designated bus lanes is a prime example. There is the suggestion of confusion and ambiguity over who is allowed to use bus lanes. Bus drivers do not tend to appreciate that cyclists have the right to use them and car drivers, on occasion, may use the bus lane to drive or park in which obstructs the right of way.

There is also a lack of appreciation of the purpose of ASLs for cyclists, as the research found that drivers frequently encroach upon the cyclist priority area, or block the cycle approach lanes enabling access to it. One of the research studies found that an average of 22.8% of motor vehicles encroach upon the ASL reservoir whilst waiting at the traffic lights.

Therefore, it may be that in some instances where facilities are found not to be performing as anticipated, improvements to user education would be a more effective response than redesign of facility. Conversely, although a widely legible design of facilities may seem *prima facie* to be desirable, the possibility should not be overlooked that a degree of uncertainty, among all users, may have positive effects if it encourages cautious behaviour. Some evidence that this might be the case may be inferred from some of the results of the studies where the provision of guidance on the 'ownership' of space, such as cycle lanes through road narrowings, seemed to result in negative behaviours such as closer cycle positioning to nearside kerbs and closer passing distances among drivers. Similarly, it may be, although this was not established by this study, that providing better delineated cycle routes through VRAs might increase cyclists' sense of entitlement to that space and therefore

reduce their willingness to modify their behaviour when pedestrians intrude. Nevertheless, where conditions are not readily legible the process of negotiating ownership may be highly stressful for users, particularly of vulnerable modes and in circumstances where speed differentials are high. This principle of the value of negotiation in low speed environments is one of the concepts that underpins home zones. More research is necessary to establish whether it is transferable to the general highway, and what the thresholds of speed and willingness to concede priority might be. Nevertheless, this may represent a fruitful line of approach.

Another significant finding of the research, specifically from the study of the cycle track in Royal College Street, Camden was that some cyclists failed to recognise pedestrians' right of way, which in those circumstances, occurred at a bus stop. Additionally, car drivers noted that there were ineligible users of the cycle track, including pedestrians and motorcyclists.

With regard to cycle track crossings, there can be confusion over the ownership of space due to the site characteristics, and this needs to be addressed. Priority can vary between cyclists, vehicles and pedestrians, resulting in potential conflict if the rules at a particular site are not known or understood.

The potential re-design of roundabouts into a 'continental' style making them safer for cyclists necessitates education on their use for each type of user because their appearance differs markedly from traditional UK style roundabouts, and the research discovered confusion among users.

The imposition of an annular cycle lane on the roundabout marked in red (which, it should be noted, is not a specific continental roundabout feature) was found to improve driver awareness of cyclists using the junction and discouraged them from overshooting the give-way line.

The main objective is to challenge existing perceptions of priority and ownership of a particular environment, or situation potentially involving cyclists, and to create an understanding and an awareness of the 'rules'.

There is also a need for education in relation to vehicle restricted areas. This environment is highly liable to conflict over perceptions and ownership of space between cyclists and pedestrians. Cyclists believed there was inadequate signing to make users aware of other types of user using the space. This need for signing should be reinforced with an educational awareness of potential users of VRAs.

5.4 Enforcement

The Cycle Facilities and Engineering project identified that for the overall success of the infrastructure, a suitable level of enforcement must be maintained. The following overall factors were identified:

- Clear unambiguous signing is important to provide a baseline for enforcement.
- Changes in priority must be enforced by gateways or barriers (VRAs, for example).
- Local authorities may elect to conduct their own observation surveys to assess the level of enforcement required.
- There is a need to restrict cars from encroaching into cyclists' space on continental style roundabouts, cycle tracks crossing minor roads, or at advanced stop lines, for example.
- There is a requirement for the police to enforce any existing bans or allocation of carriageway space.

It is important that enforcement measures work in conjunction with both engineering practices and education to reduce ambiguity across cycling infrastructure, in general. The Highway Code and design guidelines must reinforce regulations. For example, where cyclists use bus lanes there is a mutual requirement for bus drivers, motorists, cyclists and the enforcement body (police) to understand the behaviour of the users involved.

In summary, there is a need to increase the currently low level of traffic law enforcement for both drivers and cyclists.

In terms of the framework set out above, it seems notable that the most consistently successful facilities, bus lanes, the Royal College Street cycle track and advanced stop lines, were those that fit most clearly into the category of measures to provide advantage to cyclists. The two schemes that seemed to be, at best, only partially successful, were those that focussed on problem-solving i.e. the various measures at road narrowings and the use of continental roundabout geometries. This is interesting in that it suggests that the most successful 'problem solving' strategy for cycle users may be to take steps to reduce the likelihood of problems being introduced at all, rather than allowing them to occur but trying to mitigate them. This, in turn, implies that greater weight should be accorded to the use of tools such as Cycle Audit where new schemes are brought forward. Moreover, efforts should be made to ensure that general highway engineers are aware of the requirements of cycle users and of the consequences of introducing some schemes on the highway.

Those schemes that were less successful, both objectively and in terms of the reactions of cycle users, were those that failed to manage the use of space effectively. That this was variable, particularly in the case of continental style roundabouts, indicates that this is less a matter of inherently good or bad types of facility than of outcomes in the context of site-specific characteristics. However, this is an important principle that has been demonstrated in this project, and that should be applied to all types of facility, regardless of location characteristics.

An extrapolation of this logic would suggest that the most desirable cycle facilities are therefore those that deliver the greatest degree of segregation between cycle users and other road users. This may ideally be the case, however in the UK context there is frequently an inherent tension between segregation to increase perceived or actual safety of cycle users and some of the other necessary characteristics of cycle route networks, such as coherence and directness. Particularly in urban areas, the ultimate constraint is often the availability of space in which to accommodate the necessary range of modes and activities and therefore, highway space is often required to perform several functions including carriage of different modes, parking, delivery loading/unloading and accommodation of

pedestrian crossing facilities. Because of this multiplicity of uses it is rare that fully segregated facilities such as the Royal College Street Cycle Track can be provided. This is particularly the case given the desirability of consistency in cycle routes and the desire for continuity. Thus, where space is constrained, it is frequently considered impossible to attempt to reserve space, by whatever means, for the use of cyclists. Situations such as cycle lanes which end prior to, and resume after, pedestrian refuges and those that are ended prior to junctions in order to maintain junction capacity illustrate this difficulty.

In discussing the spatial characteristics of cycle-specific facilities, however, it is important to remember that the reduction of proximity between cyclists and other users only addresses one component of the conflict that may exist between users. Reduction of speed differential by slowing cyclists (in VRAs) or motorised vehicles in general, and the reduction in volume of other users are also viable strategies in particular circumstances. These approaches should be given a high priority by highway designers since they can obviate some of the difficulties that arise from a lack of available space in which to actively locate different users. This reinforces the importance of the 'hierarchy of solutions' approach to assessing opportunities to improve the performance of cycle route networks. An over-reliance on 'cycle facilities', as opposed to general highway and traffic management features, to create cycle route networks may be to overlook more effective methods available to designers. Therefore the development of cycle route networks ought ideally to be considered an integral element of the management and function of the highway network and planned for accordingly. The second guiding principle that emerges from this work is therefore that speed control and compliance, effectively enforced, must be the functional complement of successful facility provision, and perhaps this holds the key to any significant modal shift.

This may present difficulties where the provision of cycle-friendly networks is perceived to be in opposition to the existing use of networks by vehicles. These studies have shown that specific cycle facilities and other features can be used in order to improve the function of cycle routes. They have also indicated, however, that cycle facilities are not inherently effective or useful. In conclusion, it is our assessment that the difference between the two is one of commitment and willingness to take decisive action to secure space for cyclists and other sustainable modes from general highway traffic. To this extent, the challenge for those agencies charged with delivering increases in cycle use is not a purely technical one but, in conditions of congested and constrained space, has a strong political dimension.

6 Recommendations

This section provides a detailed account of recommendations and suggestions drawn out of the research projects that could be employed to improve the environment for cyclists. These recommendations act to encourage cycling for all trip purposes and to make it a safer and more appealing mode of transport.

6.1 Engineering practice

Although it must be noted that none of the cycle facilities or engineering measures studied could be said to have been enormously successful, the reports made certain key recommendations concerning the design of future cycle facilities. For example, it was recommended that bus lanes should be at least 4 metres wide where cyclists use them and that VRAs should attempt to incorporate wide spaces and definition between the footway and carriageway where cyclists are to be permitted entry.

However, these recommendations which are based on the research evidence tend to be suggestions rather than universally applicable rules. They may help to ensure that facilities are designed and built to the best possible standards, but they do not account for specific site characteristics. The nature of individual sites and the behaviour of local users need to be taken into consideration when designing a cycle facility, as it may be these which have the greatest impact on its success. This is probably best illustrated by the study of cycle track crossings of minor roads, where it was indicated that where crossings are introduced, the safest design option will depend on a variety of site specific factors including:

- Flows of vehicles into and out of the minor road.
- Visibility from the minor road to the major road.
- Traffic flows and speeds on the major road, and gaps in flow.
- Availability of land to bend out the cycle track crossing.

Furthermore, the individual scheme reports also indicated that increased complexity in the design of facilities can lead to greater hazards for cyclists. This concern was exemplified in the study of continental style roundabouts where conversion to a 'continental' style was said to benefit cyclists only where flows were relatively low. Increasing the complexity of these roundabouts in some cases led to cyclists feeling more intimidated and threatened. The cyclists at road narrowings report identified the emotional impact of the facility upon cyclists. Similarly, the study of the cycle track in Royal College Street, Camden indicated that this facility actually introduced additional complexity and, therefore, new potential conflicts and hazards. It is for this reason, that it is advised that all options are considered when designing a new cycle facility, and wherever possible, the first step should be to improve the existing cycling environment.

Additionally, the research proposed that in some situations the requirements of cyclists are subjugated in preference to those of other users. Consequently, the re-allocation of space for the benefit of cyclists is another important issue that needs to be considered in future engineering practice. The benefits of re-allocating this space to cyclists were illustrated in the reports on cycling in bus lanes and ASLs, where the majority of cyclists expressed favourable responses concerning the facilities because of the reallocation of space to them as users, enabling journey time reduction and priority.

As a consequence of the above issues and concerns it is evident that more engineering studies are needed to assist

with the design of cycle facilities. These studies will be especially useful if they take account of local conditions or focus upon issues such as junction radii, traffic flows, visibility splays, traffic speeds and road widths. Such a combination of specific and generalised research will greatly help to inform the design of cycle facilities and ensure that cycling is a properly recognised mode.

6.2 Education

In all incidences studied in the research, some form of education would have greatly contributed towards a better understanding of the environment and the correct way to negotiate it.

General educational measures should include:

- Traffic Advisory Leaflets (TALs) on cycling to educate the designer in putting into place the most appropriate measures.
- Improved signing to warn users of potential interaction between cyclists, pedestrians and drivers depending upon the situation.
- Information leaflets for all engineering measures and made available to all types of potential user to raise awareness and understanding.
- Updating of the Highway Code and create relevant design guidelines available to all transport planners.
- Imposing warning signs where necessary to warn users of a particularly vulnerable user group i.e. warn cyclists of pedestrians in VRAs.
- Publicising of the developments before and as they happen in the local area.

Table 3 shows the specific educational measures required for each type of development researched.

Education and promotion are important in overcoming attitudinal and institutional barriers. The imposition of appropriate education measures is a key factor in ensuring the effectiveness of any scheme.

6.3 Enforcement

In order for infrastructure covered by this research and its consequent scenarios to be effective, suitable enforcement strategies must operate in conjunction with engineering practice and education. The need for enforcement or factors relating to it have been identified as follows: although not all are mentioned in each circumstance, the generic application of such measures would benefit the overall cycling environment:

- Clear, unambiguous signing is important.
- Change in priorities needs to be enforced by gates or barriers (VRAs, for example).
- Police must enforce any measures where specific rules and regulations apply.
- Prevent cars encroaching into cyclists' space and edging over give-way markings at exits (for example, continental style roundabouts, cycle track crossings of minor roads, advanced stop lines, cyclists at road narrowings).
- Update the Highway Code and Design guidelines to reinforce new layouts (for example, the behaviour of drivers, buses and cyclists when cycling in a bus lane).

Enforcement must work alongside education and engineering practice to ensure against ambiguity in understanding and interpreting the various cycling facilities.

Table 3 Education measures required for development of cycling infrastructure

Issue	*Measure*
Bus lanes	Bus drivers to be educated by seminars/training of potential for cyclists to use bus lanes and methods of approaching the interaction.
	Guidance leaflet on the correct use of bus lanes
Advanced stop lines	Signs indicating cycle approach lane and drivers to stop before ASL.
	Guidance leaflet on the correct use of advanced stop lines
Cycle track crossings	Specific guide on priority of user depending upon arrangement (see TSRGD, 2002)
	Guidance leaflet on the correct use of cycle track crossings
Continental style roundabouts	Potential warning signs on and approaching roundabouts of potential cyclists in the vicinity
	Guidance leaflet on the correct use of continental style roundabouts (as opposed to UK roundabouts)
Vehicle restricted areas	Guidance leaflet on the correct use of vehicle restricted areas. Ensure, as required, signs on all entry points to a VRA to detail acceptable users of the environment across the day
	Publicity of the allowed users of the VRA.
Cyclists at road narrowings	Be wary over the implementation of warning signs as they may, in some contexts, have unexpected effects and influence driver reactions.

7 Conclusions

This overview report has served to draw together the Cycle Facilities and Engineering research projects towards making key recommendations for advancing the methods and implementation of cycle facilities along designed cycle routes and networks. There is a need to change the way of thinking and the attitudes and priorities in cycle facility provision. The effective use of measures through engineering, education and enforcement is crucial in creating infrastructure which is cycle-friendly and encourages cycle use.

The effectiveness of any facility, or a combination of facilities, along a specified route is of key importance and is subject to the requirements of the local context. Any scheme will only be effective if the entire process is kept within context and serves to meet the specific needs of the users.

The recommendations made in Chapter 6 are supported by the recommendations from the research into Drivers' Perceptions of Cyclists (Basford *et al.*, 2002) and provide a basis on which to conduct future research in the field:

- Physical road features that force cyclists and drivers into close proximity should be avoided, or where this is unavoidable, motor vehicle speeds at such locations should be reduced.
- Highway designs that deliberately require cyclists to obstruct traffic in order to produce a traffic calming effect should be avoided as they are likely to cause particular frustration to drivers.
- Education of drivers should focus not on helping them to predict cyclist behaviour, but on understanding the circumstances, including driver behaviour, that will influence cyclist behaviour.
- Training to improve awareness of required behaviours at road features and cyclist facilities may be helpful for both drivers and cyclists.
- The currently low level of enforcement of traffic law with regard to both drivers and cyclists should be increased.
- Further research should be conducted in order to establish whether the frustration experienced by drivers is translated into negative behaviour.
- Further research into the regional variations in attitude to cyclists may be useful in identifying practices likely to promote a better relationship between cycle users and motorists.

This research indicates that better co-ordinated thinking and an improved understanding of the needs of cyclists within differing environments may contribute towards the achievement of a more sustainable and progressive increase in cycle use.

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Abstract

In order to support government initiatives to encourage cycling, the DfT commissioned TRL to carry out a series of research projects into road network facilities for cyclists. These were grouped under the heading Cycle Facilities and Engineering and included:

- Cycling in bus lanes.
- An assessment of the cycle track in Royal College Street, Camden.
- Capacity implications of Advanced Stop Lines for cyclists.
- Cycle track crossings of minor roads.
- Cyclists and 'continental' style roundabouts.
- Cycling in vehicle restricted areas.
- The effects of road narrowings on cyclists.

The projects resulted in individually published reports on their findings, but certain aspects of the results were found to be common to several projects. This summary report considers the findings of the individual projects and identifies the common threads. These are discussed and developed as the basis of recommendations for improving the network from a cycling perspective, and supporting the overall sustainable policy objectives.

Related publications

TRL621 *The effect of road narrowings on cyclists* by A Gibbard, S Reid, J Mitchell, B Lawton, E Brown and H Harper. 2004 (price £40, code HX)

TRL617 *An assessment of the cycle track in Royal College Street, Camden* by S Gray, A Gibbard and H Harper. 2004 (price £40, code HX)

TRL610 *Cycling in bus lanes* by S J Reid and N Guthrie. 2004 (price £40, code HX)

TRL585 *Capacity implications of Advanced Stop Lines for cyclists* by G T Wall, D G Davies and M Crabtree. 2003 (price £40, code JX)

TRL584 *Cyclists and 'continental' style roundabouts: report on four trial sites* by B J Lawton, P J Webb, G T Wall and D Davies (price £40, code HX)

TRL583 *Cycling in vehicle restricted areas* by D G Davies, L Chinn, G S Buckle and S J Reid. 2003 (price £30, code EX)

TRL462 *Cycle track crossings of minor roads* by A Pedler, and D G Davies. 2000 (price £25, code E)

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