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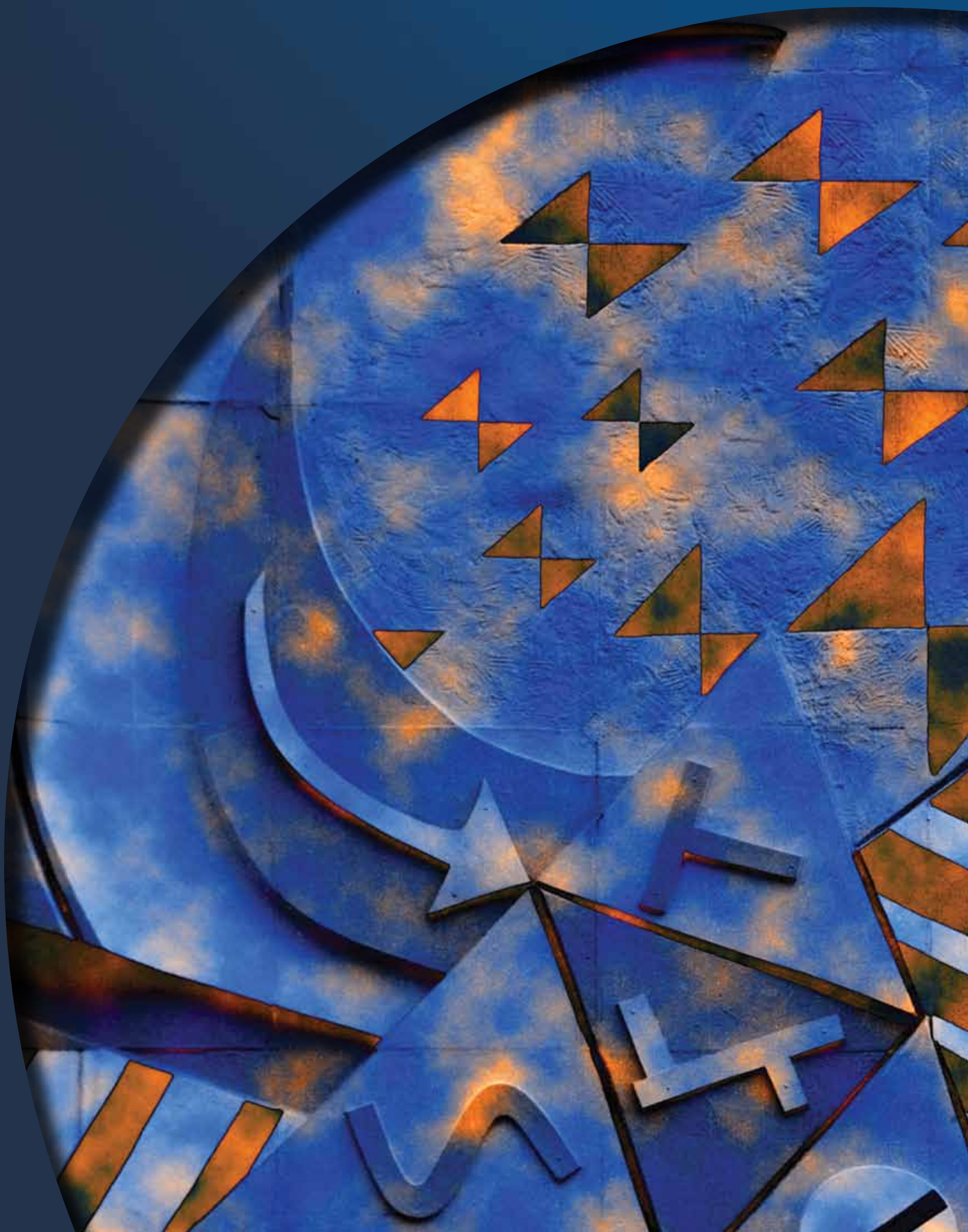
PPR580

Creating the future of transport

Infrastructure and cyclist safety

S Reid and S Adams



Transport Research Laboratory

FINAL PROJECT REPORT PPR580

Infrastructure and cyclist safety

by Stuart Reid and Simon Adams (MVA Consultancy)

Prepared for: Project Record: **Client's Project Reference No. PPRO 4/1/44**

Road User Safety and Cycling

Client: **Department for Transport**

This Draft Report has been prepared for Client's Organisation for the sole purpose of Project Report Review. It may only be disseminated once it has been completed and issued with a final TRL Report Number.

The views expressed are those of the authors and not necessarily those of Client's Organisation.

	Name	Date Approved
Project Manager	David Ham	
Technical Referee	Tracy Savill	

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Contents

Summary

This review considers the role of infrastructure in the causation and reduction of injuries to cyclists. It was undertaken as part of the wider research programme, Road User Safety and Cycling, being led by TRL on behalf of the Department for Transport.

This integrated research programme has assessed a range of road user safety topics in relation to cycling, including:

- analysis of cycling activity and collision data;
- qualitative research with cyclists and other road users;
- review of infrastructure provision; and
- review of the effectiveness of cycle helmets in reducing injuries.

As part of this programme, an international review of literature was undertaken to establish what is already known about casualties involving cyclists. This report specifically covers literature relating to the influence of infrastructure on cycle casualties, focussing on the context in which injuries to cyclists happen and can be reduced. To draw a hard distinction between infrastructure and behaviour is problematic. Casualty outcomes are primarily the consequence of human behaviour in a context formed by infrastructure, law and culture and the behaviour of other road users. Therefore this paper also identifies the influence of infrastructure on intermediate, behavioural, outcomes which may influence casualty risk, such as the speed of motorised traffic, cyclist route choice and manoeuvres etc.

Much of the literature reviewed relates to research carried out overseas. It is important to recognise that there may be important differences between countries which should be taken into account when making comparisons with the UK situation.

Overall, it proved problematic to draw definitive conclusions from the literature. Firstly, this is because the range of literature on any one type of infrastructure tends to be relatively limited. Secondly, the studies described in the literature are often relatively small-scale, both in terms of the number of locations observed and the length of the monitoring period.

There is a notable lack of evidence on the amount of cycling activity in the UK and the exposure of cyclists to different forms of infrastructure. This lack represents a serious barrier to more detailed understanding of how to reduce risk to cyclists.

Taken as a whole, the most significant infrastructure-related risk factors for cyclists in **single vehicle incidents** on highways appear to be:

- slippery road (due to weather); and
- poor or defective road surface.

For **multi-vehicle collisions** the infrastructure risk factors appear to be:

- posted speed limits; and
- encounters with other road users at junctions.

Of all interventions to increase cycle safety, the strongest evidence is for the benefits resulting from reduction in motorised vehicle speed. Interventions that achieve this are also likely to result in casualty reductions for all classes of road user.

Those intending to improve cycle safety via infrastructure need to set clear objectives and be guided by those objectives in selecting the type, and design, of infrastructure. Having intermediate behavioural objectives known to be linked to reduced risk, as well as casualty reduction objectives, is recommended and recent guidance (Helman et al, 2011) is commended to practitioners.

Junctions

Junctions are particularly associated with cyclist injuries. In order to reduce the total number of cycle casualties then interventions at junctions should be a high priority.

Reducing the speed of traffic through junctions appears to be an effective approach to reducing cycle casualties and physical calming methods are a reliable means of achieving such a reduction.

With regard to junction form, there is a convincing body of evidence that large roundabouts that maximise traffic speed and flow are a particularly risky junction type for cyclists and that the speed of motorised traffic through roundabouts is a good proxy for risk. Signalising, or possibly using more restricted geometries to reduce speed, is likely to reduce risk.

Cycle advanced stop lines (ASLs) are frequently not respected by other road users and show little safety benefit although the research in this area is particularly limited. Notwithstanding this lack of evidence, ASLs may provide a priority for cyclists and may be applicable where there are heavy flows of right-turning cyclists.

A number of infrastructure interventions have been used on the continent to increase safety at junctions that are not widely used in the UK. Particular examples include cycle lane markings continued across junctions, cycle pre-signals and Trixi mirrors (mounted below signal heads to allow drivers of heavy vehicles to see cyclists at their nearside). The literature suggests that, appropriately applied, the former two approaches can have a beneficial effect on cycle casualties. The latter is currently (2010/11) being trialled by Transport for London. Wider experimentation with these approaches in the UK is recommended.

Links

On links, although they may achieve other objectives, there is little UK evidence that marked cycle lanes provide a safety benefit and behavioural indicators such as passing distance of motorised vehicles can show deterioration in some circumstances.

Providing segregated networks may reduce risk to cyclists in general although evidence suggests that the points at which segregated networks intersect with highways offer heightened risk, potentially of sufficient magnitude to offset the safety benefits of removing cyclists from contact with vehicles in other locations. This may be particularly the case if segregated networks remove cyclists from relatively low risk links but then increase their exposure to junctions.

The nature of the segregated network is likely to influence casualty outcomes. Footway conversion and illegal footway use are identified in the literature as risky.

Segregated networks away from the highway may reduce the typical severity of casualties however the data collected nationally does not allow this to be determined reliably. Where segregated facilities away from the highway are provided the vulnerability of cyclists to poor surfaces suggests that the maintenance of such facilities is important. The detailed design of such facilities is likely to be critical to their performance.

Systemic Approaches

The evidence is strong that reducing the general speed of motorised traffic confers a safety benefit for cyclists. This may be achieved through placemaking methods, physical traffic calming and, possibly, the wider use of 20mph speed limits.

In Western Europe, network-wide segregated facilities supported by traffic calming on the highway network appears to offer an effective system-wide approach to increased levels of cycling and lower casualty risk. Piecemeal implementation of such an approach however is unlikely to be satisfactory and careful consideration needs to be given as to the best sequence in which to introduce measures. Achieving a functional network for cyclists in urban areas based on these continental principles would require:

- sustained investment over decades;
- a willingness to prioritise cycle traffic;
- A multi-faceted approach seeking to increase cycle safety and cycle use together; and
- A focus on achieving high-quality outcomes.

In addition to design, different legal conventions, particularly governing priority at junctions, may influence casualty outcomes in continental countries as opposed to the UK. The legal differences between the UK and other Western European nations have not been well documented or analysed and further consideration of this element is recommended.

Finally, there are some approaches to improving cycle safety that are in use in Europe but which are rarely used and have not been comprehensively assessed in the UK. The local authority survey described in this review identified the relatively limited repertoire of infrastructure interventions in use in the UK, with no examples given, at the time, of approaches such as general exemptions from one-way restrictions, false one-way streets etc. Given the limitations of many existing types and approaches to infrastructure, more innovation and experimentation, supported by appropriate monitoring, is recommended.

Abstract

This literature review considers the role of infrastructure in relation to the safety of cyclists and their interaction with other road users. It was undertaken as part of the wider research programme, Road User Safety and Cycling, being led by TRL. The paper identifies the influence of infrastructure on intermediate, behavioural, outcomes which may influence casualty risk, such as the speed of motorised traffic, cyclist route choice and manoeuvres etc. Of all interventions to increase cycle safety, the strongest evidence is for the benefits resulting from reduction in the general speed of motorised traffic. This may be achieved through a variety of methods including physical traffic calming; urban design that changes the appearance and pedestrian use of a street; and, possibly, the wider use of 20mph speed limits. The literature review also identifies the potential benefits of treating junctions, particularly interventions that slow the speed of motorised traffic through them. The review identifies the potential benefits of segregated networks for cyclists but notes evidence that cyclists may be exposed to heightened risk where cycle networks intersect the general highway network. The review also identifies a number of techniques to improve cyclist safety that are in use in overseas but which have not been commonly applied in the UK. Given the limitations of many existing types and approaches to infrastructure, more innovation and experimentation, supported by appropriate monitoring, is recommended.

1 Introduction

This review considers the role of infrastructure in the causation and reduction of injuries to cyclists. It has been produced as part of a programme of research carried out for the Department for Transport (DfT) into the safety of cyclists. The focus of the programme is to develop evidence that informs the DfT's objectives of reducing the number and severity of cyclist casualties whilst supporting increases in cycle use. The research assessed a range of road user safety areas in relation to cycling, including:

- analysis of cycling activity and collision data;
- qualitative research with cyclists and other road users;
- review of infrastructure provision; and
- review of the effectiveness of cycle helmets.

An international review of literature was undertaken to establish what is already known about casualties involving cyclists. The results of the review were synthesised into Knowles et al, 2009. This report has been prepared to focus more specifically on the potential for changes in infrastructure to contribute to reduced cyclist casualties, where the infrastructure relates to the physical context in which injuries to cyclists happen. Here, it includes both cycle facilities and roads with and without specific provision for cyclists. Although this report is developed under the heading of infrastructure it should be noted that infrastructure is largely passive and fixed in nature. It is the behaviour of all classes of user acting within the context of infrastructure (and cultural, legal and regulatory frameworks) that results in positive or adverse safety outcomes. Consequently improvements in safety may be measured by recording injuries sustained by road users or by assessing changes in behaviours known to influence safety outcomes.

It is also noted that, in addition to exposing users to some level of risk, regular cycle use can also result in health benefits to users. A broadly-based public health perspective on cycle use would require a relative understanding of risks and benefits. One such study, albeit several years old now, identified a 20:1 ratio of benefits to costs measured by 'life years lost and gained' (British Medical Association, 1992). This paper does not attempt such an overarching synthesis, nor does it focus on infrastructure as a means of encouraging cycle use, notwithstanding the Safety In Numbers principle[1], or increasing perceptions of safety among users, its focus is on the reduction of recorded road casualties and the promotion of behaviours known to reduce road casualty risk.

This report draws on tasks carried out under the study programme, specifically:

- an analysis of accidents involving cyclists on Britain's roads (Knowles et al, 2009);
- qualitative research on the attitudes, beliefs and motivations of cyclists and other road users (Christmas et al., 2010);
- a survey of English local highway authorities on countermeasures; and
- a review of UK and international published and grey literature on research into cyclist safety.

It is important to note that cyclists needs of, and response to, the physical environment will differ. Christmas et al's (2010) work identified four general types of cyclist by their reported behaviour with regard to motorised traffic. These were:

- Avoidance – avoid traffic completely;
- Guardedness – keep out of the way;
- Assertion – stay in control of the situation; and
- Opportunism – make the most of the bike.

It is likely that particular infrastructure solutions designed to improve cyclists' safety are more appealing, or more effective, to some of these behavioural groups than others.

An important point to note in discussing facilities generically by type is that the detailing of design, the quality of design and the effectiveness of maintenance will affect how they are used by cyclists and, potentially, their association with cyclist casualties. In most of the studies discussed in this report little specific information is given about the actual locations studied with which to form a judgement about the quality of the facility. Nevertheless, variation in quality may account for some of the variation in performance noted between facilities of ostensibly the same type that are studied in different settings.

This report is structured as follows:

[1] Discussed in an earlier report from this Programme: Knowles et al, 2009.

- Section 2 briefly summarises an analysis of police recorded cyclist casualties to identify what is known about accidents and the involvement of infrastructure;
- Section 3 presents headline conclusions obtained from a Local Authority Cycle Safety Survey;
- Section 4 summarises evidence from the published literature on the extent to which various forms of infrastructure impact on cyclist safety; and
- Section 5 discusses the results.

Appendix A outlines the literature review methodology including quality and robustness criteria.

2 The contribution of Infrastructure to cyclist casualties

This chapter summarises information about the relationship between cyclist casualties and elements of infrastructure. As previously described in Knowles et al (2009), data on the levels of cycling, the behaviour of cyclists and cyclists exposure to different aspects of infrastructure is extremely limited. This lack of evidence is a serious barrier to more detailed understanding of how to reduce risk to cyclists. Consequently in this chapter while it is possible to identify the types of location at which casualties are recorded it is not possible to identify which are relatively more risky.

Knowles et al (2009) carried out a detailed analysis of accidents involving cyclists on Britain's roads, using the police reported road casualties dataset ('STATS19', years 2005-2007). The results of most relevance to this report are summarised below:

- 74% of KSIs take place on urban roads. 48% of fatalities are on rural roads;
- 63% of all cyclist KSIs take place at junctions, the relative proportion is higher in urban areas than rural;

2.1 Single Vehicle Casualties

Single pedal cycle accidents which do not involve another vehicle are generally considered to be poorly reported in the national road accident statistics collected by the police, for example Stutts et al (1990) calculate that police reported data potentially under-represent single-vehicle on-highway incidents by more than 200%.

Analysis of police recorded (STATS19) road casualty data for 2005-2007, summarised inTable 1, indicates that single vehicle incidents (i.e. those in which no other vehicle is involved) account for 9.5% of fatal and 5.3% of serious injuries to cyclists (5.6% of KSIs overall).

A proportion of the accidents quoted in the table which involved another vehicle may not have actually involved a collision between them. For example the cyclist could have been undertaking a slower moving vehicle where there was insufficient room to pass and subsequently had to swerve and fall without actually striking the other vehicle; or a car could have pulled out in front of a cyclist causing her to take avoiding action which resulted in a fall or overturn, again without direct contact between the two.

Table 1: Involvement of Other Road Users in Fatal and Serious Cyclist Injures, 2005-2007 (STATS19 data)

Fatal	**2005**	**2006**	**2007**	**Total**
Motor Vehicle	***130***	***133***	***122***	***385***
Cycle/Cycle	***1***	***1***	***2***	***4***
Cycle/Pedestrian	***0***	***0***	***0***	***0***
Single Vehicle	17	12	12	41
Total	148	146	136	430
% Single vehicle	11.5	8.2	8.8	9.5
Serious	**2005**	**2006**	**2007**	**Total**
Motor Vehicle	2064	2157	2281	6502
Cycle/Cycle	16	17	13	46
Cycle/Pedestrian	4	9	5	18
Single Vehicle	128	113	129	370
Total	2212	2296	2428	6936
% Single vehicle	5.8	4.9	5.3	5.3
KSI	**2005**	**2006**	**2007**	**Total**
Motor Vehicle	2194	2290	2403	6887
Cycle/Cycle	17	18	15	50
Cycle/Pedestrian	4	9	5	18
Single Vehicle	145	125	141	411
Total	2360	2442	2564	7366
% Single vehicle	6.1	5.1	5.5	5.6

An alternative method of estimating injuries to cyclists is obtained from the records of people presenting themselves to hospital for treatment (which may over-represent more serious injuries). These statistics are collected in the Hospital Episode Statistics (HES) database. The majority (67%) of the on-road cyclist casualties reported in the

HES database were sustained in a non-collision accident, which includes falling from a pedal cycle or overturning. This reinforces the view with regards to the under-reporting in STATS19 for this type of accident. The HES database does not classify injuries by severity, unlike STATS19, so it is not possible to determine the relative severity of the injuries recorded in HES that were sustained in single v. multi-vehicle incidents.

Knowles et al (2009) analysed data for all single-vehicle cycle casualties over the same period (2005-2007) according to the ten contributory factors (CFs) most frequently coded in the Stats 19 database. Contributory Factors are selected from a pre-defined list. In Knowles's analysis a slightly different definition of a single-vehicle cyclist casualty was used than that of the data in Table 1. Knowles's definition was of 'pedal cyclist being injured in a non-collision accident'. This encompassed a wider definition which included all cycle accidents where a collision with another vehicle did not occur, even though other vehicles may have been present, so all the single vehicle and a proportion of the multi-vehicle collisions shown in Table 1 are summarised in Table 2. Using this approach 17% of the cyclist KSI casualties were involved in a single vehicle incident. Although the precise definition of a single vehicle incident can be debated, the overall trends with regards to the CFs are believed to be representative because the same core group of accidents are described. However, it should be noted that CFs reflect the Police Officer's opinion at the time of reporting and may not be informed by an extensive investigation. Factors are identified on the basis of evidence but are still necessarily subjective in nature. More than one CF may be attributed to any one incident.

Table 2: Most Common Contributory Factors in single vehicle accidents, 2005-2007

	Fatal	Serious	Slight
Number of cyclist casualties with CFs assigned to them	***27***	***257***	***518***
Av. number of CFs per cyclist	***1.85***	***1.44***	***1.48***
Loss of control	67%	44%	40%
Impaired by alcohol	15%	9%	13%
Other	19%	9%	9%
Slippery road (due to weather)	0%	8%	9%
Sudden braking	7%	7%	8%
Poor or defective road surface	4%	6%	6%
Travelling too fast for conditions	19%	5%	4%
Swerved	0%	5%	6%
Poor turn or manoeuvre	0%	5%	6%

Knowles et al’s analysis reveals a combination of behavioural and infrastructure factors. The contributory factor most frequently assigned in casualties of all severities is ‘loss of control’. It is not recorded in the data-set whether the design of infrastructure contributed to these incidents as such data is not routinely collected at the national level. Similarly, ‘too fast for the conditions’ does not provide any specific detail on whether infrastructure, i.e., ‘the conditions’ had an impact on the occurrence of the incident. Those almost exclusively infrastructure-related factors identified in these data relate to the surface, either its temporary condition due to weather or the quality of the road surface, suggesting that the basic design, and the management and maintenance of surfaces, drainage systems etc is an important element in cycle safety with surface defects contributing to 4% of fatal and 6% of police-recorded single-vehicle serious cyclist injuries.

The majority of recorded cycle injuries and 83% of KSIs on the highway in the police road casualty database involve at least one other road user (Knowles et al, 2009). Infrastructure may contribute to the relationship between cyclists and other road users by influencing their expectations of each other, relative positioning and behaviour.

2.2 Road Characteristics for all Cyclist Casualties

An analysis of cyclist injuries has indicated that certain locations are more frequently associated with cyclist injury. **Table 3** shows pedal cyclist casualties by road type.

Table 3: **Pedal Cyclist Casualties by Road Type, 2005-7 STATS19 Data**

	Road type	Killed	KSI	Slight
Urban areas	Major	27%	29%	31%
	Minor	25%	44%	52%
	All	52%	74%	83%
Rural areas	Major	24%	11%	6.%
	Minor	23%	15%	11%
	All	48%	26%	17%
All areas	All roads (=100%)	430	7,366	41,586

Notwithstanding the lack of exposure data, this suggests that casualties to cyclists in rural areas are more likely to be serious, representing approximately half of all fatal casualties but only 17% of slight injuries.

In addition to physical infrastructure, regulation of motor vehicle speed is also associated with different patterns of cyclist injuries. **Table 4** summarises STATS19 data for 2005-2007, representing the proportion of cyclist casualties by severity and the speed limit of the roads where they occur. This does not allow for the relative occurrence of different speed limits nor of the exposure of cyclists to different speed limits, for which no reliable data are available.

Table 4: **Pedal Cyclist Casualties by Speed Limit, 2005-7 STATS19 Data**

Posted speed limit	Killed	KSI	Slight
20	1%	1%	1%
30	53%	78%	87%
40	10%	7%	6%
50	3%	1%	1%
60	25%	11%	5%
70	8%	2%	1%
All speed limits	430	7,366	41,586

Taken as a whole these UK data suggest that:

- The lack of detailed exposure data is a major impediment to more detailed understanding of risk to cyclists;
- Surface quality and maintenance is an important element in single-vehicle incidents that result in cyclists being injured; and
- Junctions are riskier than links for cyclists.

3 Local Authority Cycle Safety Survey

As part of the DfT funded programme of research into cyclist safety, a survey was undertaken in 2008 of UK Local Highway Authorities. The purpose of the survey was to gather detailed local information on:

- what is being done at the local level to reduce cyclist casualties;
- what types of interventions are being used to influence cycle safety; and
- what further guidance is required on how to improve cycle safety.

A questionnaire was sent out in a hardcopy paper format and was accompanied by a detailed covering letter and two-page project summary. Recipients were invited to complete the questionnaire either as a hardcopy (freepost) or over the telephone.

Two copies of the questionnaire were sent to each Authority – one each to the relevant Road Safety Officer and Cycling Officer. This was to enable different internal stakeholders to answer the questionnaire and so provide alternative viewpoints.

The survey included a question which asked respondents 'which infrastructure interventions have you used to help reduce cycle casualties in your authority'. **Sixty** responses from 59 local authorities were received to this part of the survey giving a headline response rate of 29%. The respondents represented a broad cross-section, both in terms of geographical area across Great Britain and also whether the authority can be typified as 'urban', 'rural' or 'urban/rural mix'. Of the 60 responses, 60% were from Road Safety Officers and 17% were from Cycle Officers. The remaining 23% of respondents provided an ambiguous response for their job title (eg Transport Planner, Senior Engineer).

Behavioural outcomes

It is clear from the results of the survey that a wide range of different interventions have been adopted across the country to improve cyclists' safety. However many of the qualitative responses given about why a particular intervention had been made referred to concepts that were not as simply straightforward as 'reducing the risk of cycle accidents'. Instead a variety of responses were given that referred to a range of wider behavioural aspirations – an example being "limiting the number and/or speed of vehicles at junctions".

A recent guide (Helman, et al., 2011) has been produced to assist local authorities to use behavioural measures in the evaluation of road safety schemes. The report states that "there are a number of behaviours that are either known or strongly suspected to be linked to collision risk" (ibid.: p.1) and it is these behaviours that can be assessed in conjunction with conventional accident data analysis. Such an approach explicitly considers behavioural change and risk-management rather than just the 'end goal' of casualty reduction and is a useful way of framing responses in the rest of this chapter.

Below is a summary of the different infrastructure 'interventions' that have been adopted by the various local authorities who responded to the survey.

No Interventions Used

One authority stated that they had not used any infrastructure interventions to specifically reduce cycle accidents.

Cycle Lanes (on-road)

Thirty-four of the authorities responding had used cycle lanes on the road. In four of these cases the cycle lanes were advisory and were used both along roads and at junctions. Only two of the authorities stated why they had used advisory cycle lanes and their responses were:

- Protecting cyclists from traffic/ improving the conditions for cyclists; and
- Queues at junctions so advisory cycle lane means cyclists are not held up.

Cycle lanes and cycle lane networks were also cited as examples of cycle lane infrastructure, the only reasons given for implementing this infrastructure was that it was believed to improve safety for journeys to school. One authority stated that they use 'indicative routes' where advice is given to cyclists regarding more appropriate routes.

The use of on-road cycle lanes was generally considered to be at least slightly effective with 14 authorities considering the measures slightly effective and a further 4 authorities considering them to be very effective. In the case of five authorities they considered it to be too early to tell the effectiveness of measures and only one authority stated that they believed the use of an on-road cycle lane had been slightly ineffective.

The following reasons were given by local authorities to support their view that on-road cycle lanes are effective:

- The visible presence of cycle lanes has increased safety and the clearly marked area is respected by most drivers;
- Speed reduction has led to casualty reduction;
- Takes cyclists away from more heavily trafficked routes;
- Raised awareness of drivers joining main road along with the driver's awareness of cyclists on the road; and
- Road markings provide a visual barrier.

Three authorities commented on the perceived ineffectiveness or problems relating to on-road cycle lanes but only one gave a specific reason for their rating (parked cars blocking the lanes).

Cycle Paths/ Track (off-road)

There were 38 respondents who stated that they had used off-road cycle tracks to help reduce casualties.

The most common examples of off road cycle paths were those through parks, along promenades, alongside carriageways and shared use paths (10 out of 16 examples).

Three main reasons (from five respondents) for using cycle paths/track were given:

- To provide segregated routes and/or provide a traffic free environment;
- To improve safety; and

- Taking cyclists away from main ring-road eases traffic flow and cyclists can be taken away from traffic without increasing the length of their journey.

As with on-road cycle lanes, the off-road cycle tracks were considered to be at least slightly effective by the majority (18 of 27 respondents) of local authority respondents. Only two respondents considered cycle tracks to be slightly ineffective, while 7 authorities stated that the effects were unclear or it was too early to tell what the effects were.

The main reasons stated for the effectiveness of cycle tracks included:

- Provision of a safer route;
- Increased levels of cycling;
- Segregation of cyclists from traffic;
- Provision of new/alternative routes to schools; and
- Provision of more direct routes.

Two respondents gave reasons for believing this type of intervention is not so effective: cycle tracks may increase accidents and the level of effectiveness is affected by the local design/structure of such tracks.

Advanced Stop Lines

Thirty-two authorities used advanced stop lines (ASLs). The main examples given related to the use of ASLs at various signalised junctions in order to assist cyclists and to ensure that they assume the correct position at junctions. In one case ASLs were currently being installed with another authority stating that they use ASLs to provide a continuous on-road cycle route with the additional priority at junctions.

The seven reasons given for using ASLs were varied, with all seven responses being different:

- Cycle route is on a busy distributor road round shopping centre with many traffic lights;
- Important for increasing cycling and cycling to work for motorists;
- To address crashes;
- Aids progression in busy 1 way system;
- Enhances cyclists visibility at traffic light junctions;
- Council policy; and
- To segregate traffic.

ASLs were considered by 14 of the 21 respondents to be at least slightly effective, although there were three authorities that considered ASLs to result in no change to cyclist casualties. Only one authority considered ASLs to be slightly ineffective, while the remaining four stated that their effectiveness was currently unclear.

It was believed that they help increase cycling levels, especially in key transport corridors and aid collision avoidance by ensuring cyclists are more visible, giving them priority at junctions, especially where going straight ahead or making right turns.

Two perceived problems were also noted regarding the use of ASLs: they may not be understood by cyclists and consequently are not always used, and they are not always respected by motorists.

Crossing Facilities

Thirty-five Local Authorities stated that they had installed crossing facilities for cyclists. The most commonly used form of crossing was toucan crossings.

The reasons given for the use of crossing facilities included:

- Reducing the number of pedestrian accidents and providing links between shared footways across busy roads;
- Providing a cycle route alternative to a ring road;
- Avoids cyclists having to use busy dual carriageways or enables cyclists to cross busy roads safely; and
- Provides a link along a safer route to school.

Crossing facilities were considered by most respondents to be effective (17 of 23 respondents). None of the respondents considered the facilities to be ineffective, although two authorities considered that they had not resulted in any change in casualties.

Only one comment identifying a problem with crossing facilities was recorded: that most people do not differentiate between the different types of crossing.

Other Junction Improvements

A total of 25 authorities stated that they had also made other junction improvements to help reduce cycle casualties. A relatively diverse range of responses was received in terms of what the improvements actually were. The most common response involved some sort of cycle lane through the junction or provision of off-road facilities at the junctions. In one case road markings were added in order to 'guide' cyclists across junctions, whilst elsewhere guard railings were removed in order to improve visibility for cyclists.

The reasons given for these improvements included:

- Avoiding having to go around roundabouts;
- Improving pedestrian and cycle access;
- Improving safety; and
- Limiting the number and/or speed of vehicles at junctions.

None of the improvements were rated as being ineffective, although four respondents felt that their effectiveness was unclear. The remaining 13 authorities found their junction improvements to have been slightly (6) or very (7) effective.

The reasons for the effectiveness of the improvements made included:

- Facilitation of cycle movement in key transport corridors;
- Increase in pedestrian/cycle use;
- Traffic exclusion/reduction;
- Decrease in conflict at junction;

- Better sightlines benefit cyclists and other road users while road markings provide a 'visual' island in the centre of the road;
- Prevents cars cutting the corner in the path of cyclists; and
- Enables cyclists to use a large roundabout safely which was previously difficult

Traffic Calming Infrastructure

Twenty-nine authorities had used some sort of traffic calming infrastructure, the most popular examples being:

- Speed cushions, humps and sinusoidal humps;
- Traffic calming schemes on cycle routes; and
- The use of raised tables at junctions.

Two respondents gave a specific reason for their use:

- Slower/ restricted traffic speeds benefit cyclists; and
- Helping to ensure that the movement of cycles is not compromised.

Two thirds of the respondents considered the speed calming measures implemented to be slightly (10 of 21) or very (4) effective. Five local authorities were not yet clear about the effectiveness of the measures, while one authority considered the intervention to be very ineffective and another considered them to be slightly ineffective (no reasons given).

Reasons given for the perceived effectiveness of the measures included:

- Reduction in traffic and bus speeds;
- Slower speeds generally reducing both the risk and severity of accidents; and
- The uncertainty for drivers associated with road calming measures promotes safer and less aggressive driving.

20mph Zones

20mph zones have been used by 34 of the questionnaire respondents. The most common example of such measures in the sample was for the zones to be located near to schools, in some cases as part of safer routes to schools initiatives.

Some felt the use of advisory signs may promote safer driving in the vicinity of schools.

Safer Routes to Schools

Thirty-six respondents had used some sort of measures relating to Safer Routes to School, the provision of a cycle path network linked to schools being the most frequently cited example.

Three quarters of the respondents rated safer routes to schools measures as either slightly (11) or very (6) effective. One Local Authority considered there to have been no change while the other five did not have any clear indication on the effectiveness of the measures.

The reasons cited for the perceived effectiveness of the various measures include:

- Increased cycling to school, along with increased confidence when walking or cycling to school using the routes;
- The opportunity to train the cyclist of the future;
- Keeping pupils away from busy roads while also reducing clutter on the footways;
- Identifying the issues and concerns related to the journey to school; and
- Promoting healthy lifestyle choices.

Summary

Taken as whole, the interventions used by local authorities represent four broad approaches:

- mediating the interaction of cyclists and other road users at junctions and other points where cyclists' desire-lines conflict with motor vehicles;
- removing cyclists from conflict with motor vehicles by creating alternative routes or networks for cycling;
- reserving space for cyclists within the carriageway on either an advisory or compulsory basis; and
- measures to reduce traffic speed.

There are mixed views reported by respondents as to the effectiveness of the interventions they have adopted with a common reply being insufficient time and/or data to fully assess a scheme's outcome. Because of this lack of robust before and after evaluation, responses on the effectiveness of schemes were often subjective rather than being objectively based on actual measurements and data.

A greater emphasis on evaluation, including using behavioural indicators such as reduced traffic speeds is recommended as being appropriate. Assessing scheme outcomes using a behavioural-based approach (eg Helman et al., 2011) provides a more nuanced approach that combines behavioural change in conjunction with conventional accident data analysis. This would seem to be a useful way of establishing whether a scheme is providing the desired impacts.

Finally it is noted that authorities appear to be confined to a limited repertoire of infrastructure interventions to improve cyclist safety. Respondents were offered open-ended questions to identify other methods that they were using to increase cycle safety, a number of responses were offered but these all focussed on behavioural interventions, with no innovative types of, or approaches to, infrastructure identified.

4 Summary of Published Evidence on the Contribution of Infrastructure to Cyclist Safety

Based on the literature reviewed, the evidence for the effectiveness of infrastructure interventions in reducing casualties is summarised in this chapter.

4.1 Junctions

Police recorded road casualty data for 2005-07 indicate that the majority (63%) of collisions between cyclists and other users, in both urban and rural situations, take place at junctions (Knowles et al, 2009). This compares with 59.9% of all accidents (excluding those taking place on Motorways) of all users at junctions over the same period. This is similar to the findings of Stone and Broughton (2002) who examined police accident statistics between 1990 and 1999 and found that over 70% of bicycle-related injuries occurred at or within 20 metres of a junction. Over half of these were at T junctions. These accidents occur mostly as a result of motorists emerging from side roads or turning into them and colliding with cyclists (Pedler and Davies, 2000).

Limited information on the distribution of different junction types and cyclists' use of them is available. It is therefore not possible to determine which junctions are most risky relative to one another. However there is evidence that large roundabouts are particularly risky for cyclists (see Section 4.1.3).

Stone and Broughton (2002) introduce a 'theoretical invariance' concept to provide a potential control for exposure to different situations in order to compare the relative riskiness of different manoeuvres at specific junction types. At T junctions they identify the most risky manoeuvres as being those where motorists turn right into or out of a side-road across the path of a cyclists travelling in the opposing direction. At crossroads situations in which the cyclist approaches towards the left of the vehicle are marginally more risky (ratio 1.2) than those where the cyclist approaches from the right. At roundabouts the most risky situations are those where a cyclist on the roundabout crosses the path of a vehicle entering the roundabout which is travelling straight ahead (i.e. not turning), followed by those where the vehicle travelling straight ahead overtakes a cyclist travelling straight ahead. Stone and Broughton acknowledge that the reliability of these results is dependent on their underpinning assumptions regarding exposure.

4.1.1 Uncontrolled Junctions

Wood et al (2006) studied the effect of raised 'side road entry treatments' (SRETs) in London. These features are primarily intended to provide a facility for pedestrians and do not necessarily form part of the infrastructure of a segregated cycle track. They consist of a flat-topped raised table across the mouth of a side road at its junction with a major road. The table has ramps for traffic at either side. The table links the footways at either side of the junction mouth and enables pedestrians to cross without gradient whilst encouraging a reduction in the turning-speed of motorised vehicles.

The effects on collisions were modelled by Wood et al for 777 SRETs on the Transport for London Road Network (TLRN, the strategic road network within London for which TfL is the highway authority), primarily in inner London, which had been introduced at the same time as the Red Routes (where traffic is not generally permitted to stop). Data were analysed for the 36 months before and after installation. The results at the TLRN sites may be influenced by a number of factors, including the simultaneous implementation of the Red Routes. At TLRN sites there was no statistically significant change in the total number of collisions however a statistically significant reduction in cycle collisions of 20% was identified. Some other classes of collision were estimated to have increased, particularly those involving powered two wheelers.

275 SRETs were studied by Wood et al on London roads for which the relevant London Borough is the highway authority (primarily in outer London). At those sites for which 36 months before and after data were available (141) there was an estimated reduction in all collisions of 21% with a statistically significant reduction in pedal cycle collisions of 51%, with no increase in collisions among any other user group. Taken together, these results suggest that, for pedal cyclists at least, SRETs can have a clear casualty reduction benefit at uncontrolled junctions.

Where cyclists are crossing a junction mouth on a cycle track, Garder, et al. (1998) suggest that one way of improving safety is to raise the cycle crossing in a manner similar to a SRET. Garder et al studied four junctions in Gothenberg at which painted cycle crossings of side-roads at T-junctions were enhanced by raised tables of up to 12cm in height. Garder et al used a range of methods to assess changes in risk. They noted that flows of cyclists at the study sites increased in the range 75-100%, compared to 20% increases in cycle flows at control sites. The speed of turning motor vehicles at the junctions decreased by 40% to 10-15kph. Conversely cycle speed across the junction increased at one of the sites and an increased flow of cyclists travelling in the illegal direction along the track was observed. Taken as a whole, Garder et al conclude that there is a reduction in collision risk and an even greater reduction in injury risk (due to lower motor vehicle speeds) following the raising of the crossings. Garder et al use casualty data to develop an 'index of effectiveness' from which they conclude that casualties are likely to have increased at the study sites by 8% compared to a much greater increase in flow, denoting a decrease in risk. The study suggests that increased cyclist speed at junctions may have eroded some of a potentially larger risk reduction.

A method less frequently used in the UK is to continue an advisory cycle lane marking across a junction. Jensen (2008) studied the effects of such (blue) markings at junctions in Copenhagen. He concluded that, when marked in a single direction through the junction, they reduced collisions by 10%, but that marking two or more directions increased collisions. Jensen speculated that the multiple markings may have confused drivers.

Coates (1999) describes the introduction of junction cycle lane markings, with a light brown surfacing, across nine junctions in Oxford in 1992. At these sites the total cycle casualties reduced from twelve in the four years before implementation to seven in the four years after, no specific flow information is given at these sites although Coates notes that city-wide levels of cycling remained relatively stable after the mid 1980s.

4.1.2 Controlled Junctions

At signalised junctions Pucher and Buehler (2008) noted that, in continental Western Europe, the use of cycle pre-signals is common. This affords cyclists priority and the opportunity to clear junctions ahead of motorised traffic. McClintock et al (1992) described the application of such facilities in Odense and state that these have prevented (an unspecified number of) collisions between cyclists and turning traffic. There is limited application of this approach in the UK, as indicated by the local authority responses summarised in Chapter 3.

In the UK, a method used to improve cyclist safety at signalised junctions is the Advanced Stop Line (ASL). ASLs provide a stop line for motor vehicles and an additional stop line for cyclists nearer the signal heads. A lead-in lane is provided to allow cyclists to legally pass the first stop line. The area between the two stop lines forms a reservoir for waiting cyclists to occupy. ASLs cannot be used at signalised pedestrian crossings or at Give Way junctions.

Faber Maunsell (2005) found that the introduction of ASLs to junctions on the A23 and A202 in London helped to improve cyclists' perceptions of comfort and safety and were well-liked by cyclists. The report recommended that careful consideration of the access route to the ASL is important in order to maximise the use of the facility.

The proper use of ASLs by cyclists was found to be low by Atkins (2005), with cyclists waiting in front of the ASL area or jumping the lights. The report also found a high level of reservoir encroachment by powered two wheeled vehicles. However, Allen et al. (2007) found that ASLs were generally used properly by cyclists positioning themselves for a right turn.

In terms of ASL effectiveness, Atkins (2005) cites TRL's 2001 London Accident Analysis Unit study which found no significant overall accident saving following the introduction of ASLs at 50 sites in London. However, it is reported that some individual sites did see a significant decrease. It is not stated whether this study controlled for the 'regression to the mean' phenomenon.

A particular issue at junctions is the vulnerability of cyclists to heavy vehicles. Knowles et al (2009), Kim, et al (2007) and McCarthy and Gilbert (1996) found that, while most cycle accidents involve a passenger car, a high proportion of serious injuries at junctions involve heavy goods vehicles. Most such incidents occur during manoeuvres, in particular during left turns and at roundabouts (CTC, 2000). Robinson (1995) found that around half of HGV accidents resulting in cyclist injury occur when the HGV is travelling at less than 10mph. A technique that is used in some continental countries, but only recently under consideration in the UK, is the use of Trixi mirrors. These mirrors are mounted on signal poles to assist drivers of large vehicles in seeing into their nearside blind spot. Transport for London has been trialling the use of these mirrors (2010-11). No published literature assessing the effectiveness of Trixi mirrors has been identified in this review.

4.1.3 Roundabouts

Larger roundabouts, as generally designed in the UK, as distinct from mini-roundabouts, may have a number of features that maximise the flow and speed of motorised traffic: wide or multi-lane circulating carriageways, tangental approaches and flared entries and exits that minimise vehicle deflection. Such designs do not have a good safety record for cyclists. Lawton et al, (2001) found that roundabouts were the junction type with the highest proportion of cyclist accidents. Schoon and van Minnen (1994) state that, while roundabouts are known to reduce the number of motor vehicle accidents, they do not extend the same benefits to cyclists. Daniels et al (2008) studied 91 roundabouts in Flanders and found that the conversion of junctions into roundabouts produced a significant 27% increase in cycle casualties and a 41-46% increase in KSIs.

Hels & Orozova-Bekkevold’s (2007) study of 88 Danish roundabouts found little relationship between geometric design and accident numbers. The exception was ‘drive curve’, a measure of vehicle deflection at roundabouts taken as a proxy for motor vehicle speed. This was found to be correlated with cycle casualties, where the faster the (potential) motor vehicle speeds, the greater the probability and severity of cyclist casualties.

Taken together with Stone and Broughton’s work (2002, op cit) which indicates that the most risky interactions of cyclists with drivers at roundabouts are when motor vehicles are travelling straight ahead (i.e. subject to the minimum deflection from a straight path) this suggests that reducing motor vehicle speed at roundabouts will reduce risk to cyclists. It has been suggested that this may be achieved by signalising the roundabout (CTC, 2000). TRL (2005) studied two London roundabouts before and after signalisation. In both cases a statistically significant decrease in cycle casualties was observed. This led the report's authors to conclude that the ‘signalisation of roundabouts can reduce the risk for cyclists and reduce casualty numbers.’ This study did not control for the 'regression to the mean' phenomenon although the signalisation was not carried out in response to a cyclist casualty hotspot.

An alternative approach to roundabout design, often referred to in the UK as ‘Continental’ features narrower circulating carriageways, perpendicular approaches and minimal flare on entry and exit. These features reduce vehicle speeds and place cyclists in a driver’s field of vision. Another feature of such roundabouts is their single entry, exit and circulating lanes which mean that cyclists cannot be overtaken whilst using the roundabout.

Lawton et al (2001) suggested that continental roundabout geometries may be safer for cyclists than typical UK designs. The approach was tested on four roundabouts in the UK which had some ‘continental’ features (Lawton et al, 2001). No significant differences were found in cycle casualties, although there was extremely limited data for the ‘after’ monitoring period. The reduction to a single lane was perceived as being safer by cyclists responding to a questionnaire survey. Overall the study concluded that only those roundabouts with relatively low vehicle flows were suitable for conversion.

An earlier study by Davies et al (1997) drew similar conclusions to Lawton et al. that modifying roundabouts to a 'continental' design may be a useful option for resolving safety problems for cyclists. Detailed computer modelling of existing and revised (continental) roundabout designs was undertaken that showed a general trend for reduced accident frequency for all road users in the revised designs.

4.2 Alternative Routes and Networks

The function of alternative routes and networks is to reduce interaction between cyclists and motorised vehicles. Although reducing cyclists’ exposure to motorised vehicles may seem likely to reduce their exposure to risk, the literature typically indicates that more than half of cyclists receiving hospital treatment are injured off-highway, eg. Turner and Roozenburg (2006), Meuleners et al. (2003), The Travers Morgan Pty Ltd (1987), Jacobson et al. (1998), Stutts et al. (1999) and Petersson et al. (1997).

Interpretation of this information is difficult since hospital data does not enable the relative severity of offroad accidents to be compared with on-road ones. Moreover, as noted by Christmas et al (2010), cyclists are not all the same and their needs of, and response to, the physical environment will differ. It is possible that particular infrastructure solutions designed to improve cyclists' safety might be more appealing, or more effective, for some of these behavioural groups (see Christmas et al, 2010) than others. This may affect the nature of the population of cyclists in different settings which may influence the pattern of casualties, for example if some types of facility appeal to less experienced cyclists who may be more prone to loss of control accidents etc. As previously noted the extremely limited information available on the population of cyclists and their exposure to different types of infrastructure makes the analysis of relative risk impossible.

Alternative routes and networks can be sub-divided into those that exist largely away from highways and those that run adjacent to carriageways.

4.2.1 Off-highway Routes

Routes and networks that are entirely off-highway may, in principle, offer cyclists safe environments in which to ride. This argument, however, is not entirely clear cut in that, as discussed above, hospital records suggest that a high proportion of cyclist injuries take place in such locations. This relationship cannot be expressed in terms of risk as data on the relative exposure of cyclists in different locations is not satisfactory (Knowles et al, 2009), neither, as discussed above, does the HES data enable the relative severity of injuries sustained on v. off highway routes to be evaluated reliably.

Studies by Franklin of segregated cycle routes (Franklin, 2002 and Franklin, 1999) relate to the Milton Keynes Redway system, a dedicated network of routes within the city. Franklin (1999) cites evidence of casualty numbers on the Redways exceeding those on the grid roads in Milton Keynes in three of the years during the period 1988 to 1997. The number of casualties also exceeded those on local roads in four years during the same period even though, according to screenline cycle counts, the Redways only carried ‘a little over half of cycling trips’.

Pedler and Davies (2000) identify infrastructure risk factors on off-highway routes which are not normally an issue on the highway, such as protruding vegetation and street furniture (eg bollards, bins, signs, seats), as well as the presence of pedestrians.

It is rarely possible, particularly in urban areas, to provide entirely segregated networks for cyclists that do not intersect with the highway network. Thus, sites where cyclists rejoin the highway will create potential for conflict. In the UK 17% of reported cyclist fatalities are sustained when cyclists are entering the road from the pavement, although not necessarily when using a designated cycling facility (Knowles et al, 2009). Cycle crossings may be provided where off-carriageway networks intersect with highways. The most common form of signalised cycle crossing in the UK is the toucan which is a crossing shared with pedestrians. Toucan crossings in the UK were studied by Taylor and Halliday (1997) who found no observed conflicts between cyclists and pedestrians using the crossings. There was no information in this study on the number of, or reduction in, collisions as a result of toucan crossings being introduced.

Although some of the evidence described above may conflate mountain biking and recreational 'play' cycling with 'purposeful' trips, studies considering commuters specifically in North America (Moritz, 1998; Aultman-Hall and Hall, 1998; Aultman-Hall and Kaltenecker, 1999) have also found mixed results, although note that these compare the risk of off-road casualties with the relative risks of roads which are somewhat different in design and operation from UK roads.

Moritz used a self-completion questionnaire from 2,374 commuter cyclists across North America and calculated a relative danger index by comparing self-reported crashes to commuter mileage on different facilities. This study concluded that off-road paths were relatively safer than on-road but that sidewalk (footway) riding was most risky of all.

Aultman-Hall and Hall (1998) and Aultman-Hall and Kaltenecker (1999) used a similar methodology to Moritz in Ottawa (1604 respondents) and Toronto (1360 respondents) and reached different conclusions. In Ottawa there was no difference in collision rates for off-road or footway cycling, but the relative risk of falls on off-road paths was 2.1 times greater than for on-road cycling without facilities. The relative risk of falls on footways was greater still at 4.0 times than for on-road cycling without facilities. Similarly, the relative risk of injury was greater for off-road paths (1.6 times greater than for on-road cycling without facilities) and greater still for footways (4.0 times greater than for on-road cycling without facilities).

In Toronto it was concluded that, compared to on-road cycling, the relative risk of collision was 3.5 times greater for off-road cycling than for on-road cycling without facilities and also for footway cycling (2.0 times greater). For injury, the risk in Toronto was calculated as being 1.8 greater for off-road paths than for on-road cycling without facilities and substantially greater for footways (6.4 times greater).

Although there may be more incidents on off-road facilities, there may still be a role for segregated networks in encouraging cycling. Christmas et al. (2010) found that some cycle users simply prefer to avoid motorised traffic altogether. This was also noted by Garrard et al. (2008), who studied the route choices of female cyclists in Melbourne at commuter times. They concluded that 'females showed a preference for using off-road paths rather than roads with no bicycle facilities, or roads with on-road bicycle lanes'. Segregated facilities may have an application in rural areas where the frequency of junctions is lower, provided that they can meet the required standards of geometry, surfacing and lighting and that consideration is given to protecting cyclists at junctions.

4.2.2 Segregated Facilities within the Highway

Segregated facilities are often provided in urban areas adjacent to carriageways and frequently take the form of converted footways.

Studies by Aultman-Hall and Hall (1998) and Aultman-Hall and Kaltenecker (1999) in North America found that footway cycling was riskier than on-carriageway, as did Moritz (1998). In the UK, Williams (1989) studied injuries to cyclists on roads with converted footways. She concluded that the introduction of a converted footway did not appear to affect the frequency of injury accidents at the 18 sites studied, nor on the adjacent carriageway. However, it was noted that changes in level of use may have masked a risk reduction benefit. It was also found that only approximately a third of the cyclists observed chose to use the converted footways (the remainder continuing to use the carriageway) and that they were found to be at risk at side road junctions.

Franklin (2002) suggests that reduced visibility, the number of junctions to cross, and obstacles such as lamp posts and signs can make riding on footways converted to shared use (walking and cycling) more hazardous than using the roadway. The points where adjacent facilities meet side road accesses and junctions appear to be a particular source of risk. Garder, et al (1998) conclude that cycle tracks without rossing facilities along arterial roads increase cyclists' risk at junctions but that risk can be reduced by providing raised crossings at side-road junctions.

Jonsson (2007) observed car drivers and cyclists at junctions between cycle paths and roads in Finland, and found that 30% of motorists did not give way to cyclists when required by law. This proportion was greater when speeds were higher or bike flow was lower. The study concluded that give way rules and even signs were insufficient to promote correct behaviour from drivers. Similar findings are presented in Rasanen et al (1999).

Rasanen and Summala (1998) studied 188 collisions between drivers and cyclists in Finland. They concluded that cyclists are often hit by cars turning across their cycle path when turning from a main road onto a minor road. Cyclists were found to overestimate the probability of drivers giving way to them: 68% of cyclists reported that they had noticed the cars before impact but 92% of these had believed that the car driver would give way as required by law.

Jensen (2007) carried out a before and after study of the effects of bicycle lanes and tracks on safety in Copenhagen. Jensen studied the performance of one-way bicycle tracks of 2-2.5m width on both sides of 20.6km of road in Copenhagen over a before and after period of 1-5 years. The study included correction factors for crash trends, traffic volumes and regression to the mean.

Jensen found that construction of bicycle tracks resulted in a 20% increase in bicycle/moped traffic mileage and a 10% decrease in the mileage of other motor vehicle traffic. This was set against an increase of c.10% of both crashes and injuries among all users. The net increase in injuries masks a statistically insignificant reduction in the number of crashes (10% reduction) and injuries (4%) reduction on links but a statistically significant increase in crashes and injuries of 18% at intersections and a 24% increase among cyclists/moped riders. This increase is noted as being especially large among women under 20 while injuries to older cyclists and children in cars are reduced. Within Jensen's data the composition of crashes also changed. There were statistically significant reductions in cars hitting bicycles/mopeds from the rear (-63%), hitting left-turning bicycles/mopeds (-41%) and between bicycles/mopeds and parked vehicles (-38%). Conversely these gains were outweighed by increases in rear-end crashes between cyclists/mopeds (+120%), with right-turning vehicles (+140%), with left-turning vehicles (48%) and with entering/exiting bus passengers.

Interestingly Jensen suggests that the prohibition of parking on arterial routes with segregated cycle tracks leads to more parking on side-streets and hence an increase in the volume of turning motor-traffic. Jensen concludes that roads with bicycle tracks and parking are safer than roads with parking bans. Jensen advises that "bicycle tracks than (sic) end at the stop line of signalised intersections with no turn lanes for motor vehicles should be avoided due to major safety problems". Jensen acknowledge that the increased cycle (and moped) traffic and reductions in the volume of other motorised vehicles are likely to have had environmental and public health benefits.

Taken as a whole the evidence regarding segregated facilities suggests that they are likely to be attractive to some cyclists but could result in a net increase in risk to cyclists unless the speed of traffic is controlled at the points where they meet the highway network.

4.3 Reserving Space Within The Carriageway

4.3.1 Cycle Lanes

The most common cycle-specific method of reserving space within a carriageway is to provide a cycle lane. This does not generally create additional carriageway width but attempts to encourage other road users to leave the space clear for cyclists

In the UK, cycle lanes may be mandatory or advisory.

Advisory lanes are often provided where there is a desire to allow kerbside parking, loading and unloading or where carriageway width is insufficient to accommodate a mandatory lane as well as large vehicles. A type of infrastructure common on the continent is an on-carriageway lane segregated from motorised traffic by a kerb. This form of cycle lane is rare in the UK, although examples have been implemented in some UK cities including London, Brighton and Cambridge. At the time of writing no published evidence has been found regarding the safety performance of kerbed cycle lanes in the UK or on the continent.

There is only limited evidence in the UK literature to show that marked cycle lanes reduce the frequency of cycle accidents and only four of the 34 local authorities responding to the local authority survey described in Chapter 3 considered them very effective.

Summarising research carried out in the United States from the 1970s to the 1990s, Reynolds et al (2009) conclude that roads with cycle lanes are relatively less risky than roads without cycle lanes. European research however is more equivocal. Coates (1999) analysed casualty data before and after the implementation of cycle lanes at 21 sites in Oxford in the 1980s. Ten were introduced in 1981 (Phase 1) and ten in 1986 (Phase 2). The analysis period was 34 months before and after implementation of Phase 1 sites and 78 months at Phase 2. Coates found a 29% increase in cycle casualties at Phase 1 sites and a 2% reduction at Phase 2 sites, against a background trend of 20% increase and 17% increase, respectively in the two Phases, within the City as a whole. No information is given regarding levels of cycling activity at any of the study sites although Coates notes that city-wide levels of cycling increased during the 1980s and remained relatively stable from the mid-1980s onward.

Jensen et al (2007) in their study of outcomes in Copenhagen concluded that marking cycle lanes resulted in a 5% increase in bicycle/moped mileage and a decrease of 1% in motor vehicle mileage. The effect on bicycle lanes in urban areas was an increase in crashes of 5% and a 15% increase in injuries.

Jensen (2007) studied cycle lanes as part of his before and after study of the performance of cycle facilities in Copenhagen. He found that marking cycle lanes of 1.5-2m on both sides of 5.6km of roads in Copenhagen resulted in a statistically insignificant increase in crashes (+5%) and injuries (15%). Safety reductions were observed on both links and at junctions. The increase in injuries was pronounced among cyclists/moped riders and was statistically significant (49%) and there was a larger increase in injuries among women than men.

The Department for Transport (DfT, 2008b) recommends absolute minimum and recommended widths for cycle lanes. Evidence suggests that these recommendations are not always met, for example those described by Parkin and Meyers (2009), below. It is possible that the inability to identify a clear casualty reduction benefit from marked cycle lanes in European research represents a lack of quality in implementation. Anecdotally such issues were raised by participants in discussion groups (Christmas, 2010) who cited instances of cycle lanes that:

- ended suddenly, leaving the cyclist having to rejoin traffic;
- were punctuated by drains and manhole covers, or poorly maintained; and
- were infringed on by traffic, or used to park cars.

In addition to any qualitative issues it is also argued by some commentators that cycle lanes also have undesirable behavioural effects on motorised vehicle drivers. For example it is argued (e.g. Franklin, 2002, Walker, 2007) that a cycle lane creates a boundary for the attention of motorists, resulting in them concentrating on what is happening in their lane instead of considering cyclists using the adjacent lane.

In a study of overtaking behaviour Walker (2007) found that, when passing a cyclist, 'to a first approximation, a driver follows the same path when overtaking a bicycle [in a cycle lane] no matter where the bicycle is.' Basford & Reid (2002) found that, in a simulator study, the presence of a cycle lane was associated with drivers passing cyclists more quickly and braking less frequently. This was even if the cyclist they encountered was not in the lane.

Parkin and Meyers (2009) measured the effect of cycle lanes on vehicle proximity to cyclists at three sites in Lancashire. The study measured overtaking behaviour on these roads on sections with and without cycle lanes although at 1.45m in width on the 40 and 50mph roads and 1.3m on the 30mph road all of the lanes studied were below the minimum standard (2m and 1.5m, respectively) recommended by the DfT (2008b) for lanes on roads with these speed limits. The sites were all virtually straight and flat in order to eliminate horizontal and vertical geometry variables. At the sites with 40 and 50 mph speed limits, on average cars passed cyclists at a greater distance (181mm and 68mm greater, respectively) where no cycle lane was present. These differences were statistically significant. No significant difference in overtaking distance was found at the 30mph site or for other vehicle types. Parkin and Meyers provide information on the measured widths of the roads at locations with and without cycle lanes. They did not find a clear relationship between total road width and passing distance, for example noting that "the significantly wider passing distance offered by motorists on the A6 at Broughton [the 40mph site] without a cycle lane is all the more noteworthy when it is realised that the carriageway without the cycle lane is 200mm narrower than the carriageway with the cycle lane". Parkin and Meyers hypothesise that, at the sites with cycle lanes, 'the driver is driving with reference to the lane lines and not to the cyclist'.

In urban areas in the UK kerbside space is often used for parking, which can interrupt or block cycle lanes. The presence of parked vehicles can reduce vehicle speeds (York et al, 2007) but deflect cyclists away from the kerb into the carriageway.

Vandebona and Kiyota (2001), cited in Turner and Binder (2009), monitored four sites in Sydney and assessed cyclist stress. This was based on observed behavioural indicators such as frequent changing of lane position, illegal footway riding, looking behind in mid-blocks and indication of loss of balance. They found that parked cars caused a high level of stress.

Turner and Binder (2009) developed a series of cyclist casualty prediction models using New Zealand data and concluded from an analysis of a range of models that 'parking does have a major effect on crash rates' of all vehicles. They found that sites where parking is marked but less heavily used had higher cyclist crash rates than locations of higher average parking use. They speculate that intermittent obstructions, causing cyclists to pull around parked cars, may surprise drivers.

4.3.2 Contraflow Cycle Lanes

Contraflow cycle routes allow cyclists to ride against the general flow of traffic in an otherwise one-way street. These may provide cyclists with shorter routes and may also enable them to avoid other routes with riskier conditions. Consideration of the safety of contra-flow needs to be informed by the safety of alternative routes that cyclists may take if contra-flow is not permitted, although relative safety of the options will clearly be highly context specific. No studies were identified that, at a network level, compared contraflow to alternative options.

The main hazard to cyclists using a contraflow is from drivers entering from side roads and failing to check both ways before pulling out (Morgan, 1995). Morgan argues that contraflow cycling may actually be safer than cycling with the flow. He states that in Germany a number of residential areas where contraflow cycling has been allowed have seen a reduction in cycle accidents, although no quantification is given.

Héran et al (2006) undertook analysis of collisions in Strasbourg between 1997 and 1999 and found that, of the 452 collisions that involved a cyclist, five occurred whilst a cyclist was travelling contra-flow. All of the five collisions occurred at junctions. The level of relative exposure for these various types of location (contra-flow, junction, other) is not reported.

4.3.3 Bus Lanes

Bus lanes also attempt to reserve space for a particular road user type. Reid and Guthrie (2004) studied cycling in bus lanes. Although casualty data could not be analysed in detail, levels of observed conflict between cyclists and other road users were found to be low. When surveyed, a large proportion of cyclists preferred the bus lane to dedicated cycle lanes. The authors hypothesised that this is because of the greater width and separation they offer from general traffic. Given the other users of bus lanes, including buses, Reid and Gutherie recommended wider bus lanes wherever possible.

4.4 Speed Reduction

Several studies have found that cyclist fatality rates are directly related to vehicle speed (Garder, 1994; Garder et al., 1998; Fernandez de Cieza et al., 1999; Stone & Broughton, 2002). Stone and Broughton (2002) studied 30,000 STATS19 police casualty records of collisions involving cyclists recorded between 1990 and 1999.

They found that 75% of fatal and serious cycle accidents occur on 30mph roads, but the fatality rate rises markedly with speed limit.

Kim et al (2007) reported that, when a motor vehicle exceeding the speed limit is involved in a collision with a cyclist, the probability of fatal injury increases by 300%.

A recent study (Richards, 2010) investigated the relationship between speed and risk of fatal injury for pedestrians and car drivers (but not cyclists). For pedestrians, fatality risk increases slowly until impact speeds of around 30 mph. Above this speed, risk increases rapidly. The increase in fatality risk is between 3.5 and 5.5 times from 30 mph to 40 mph.

Webster & Layfield's (2005) research into 20mph zones in London found that the frequency of all casualties decreased by 45% following the 20mph zones being introduced. This included a 33% reduction in total cyclist casualties, 59% decrease for child cycle casualties and a 50% reduction in cyclists killed or seriously injured (60% reduction for child KSIs).

The evidence is a strong that reducing the speed of motorised vehicles results in a reduced total number of casualties and a reduced severity of cyclist casualties.

4.4.1 Physical Traffic Calming

Effective speed reduction may be achieved by physical means that are well documented elsewhere, approaches include designing a street for lower speeds around placemaking principles (e.g. DfT 2007 and CIHT 2010) and the use of physical traffic calming measures. There is some evidence that physical traffic calming needs to be carefully designed if it is not to disadvantage cyclists.

Road narrowings can include chicanes to slow traffic, pedestrian crossing refuges and simple build-outs. They may present increased risk to cyclists where drivers choose to overtake them on the approach to (and too close to) the narrowing (Gibbard, et al., 2004).

Gibbard, et al. (2004) used a combination of video observation at 5 sites with road narrowing features and a questionnaire survey of 393 cyclists. They found road narrowings to be a source of stress to cyclists, especially where large vehicles were present, and this was exacerbated in locations where vehicle speeds were high. This often resulted in evasive behaviour, such as riding on the footway, to avoid such features.

Gibbard et al. (2004) also observed that motorists' behaviour often became more risky when encountering cyclists close to narrowings, leaving less passing clearance and exhibiting a tendency to overtake cyclists close to the narrowing.

Overall Gibbard et al conclude that cyclist stress is worsened by roads which vary in width, as opposed to continually narrow roads, due to the opportunities for inappropriate overtaking made possible by occasional increases in road width.

This fits with research by Guthrie, et al (2001) which found that the occasional vehicle passing too close was more worrying for cyclists than the average passing distance of vehicles. The provision of additional cycle facilities such as bypasses to narrowings only has a limited effect on reducing cyclists' stress levels (Gibbard, et al., 2004).

A study of road cushions found that, while cyclists could use the gap between a cushion and the kerb, they were forced to use the central gap or go over the cushion when parked cars were present. Three cushions abreast presented a more threatening situation, with a tendency for vehicles to force cyclists into the small space next to the kerb (Layfield, 1994).

Although traffic calming features require careful design, there is evidence that slower motor traffic speeds can reduce casualties for all road users, including cyclists. They may also give rise to other benefits such as increased levels of cycling (Leden, 2006).

4.4.2 Non-physical Changes

In the UK regulations require that 20mph Zones (as opposed to 20mph limits) be self-enforcing. A number of UK local highway authorities, e.g. Portsmouth, have latterly begun to adopt a blanket application of 20mph limits on residential roads without physical calming measures. At the time of writing, the effectiveness of this approach has not been thoroughly evaluated. An interim evaluation (DfT, 2010) found that the average speed reduction at all sites monitored was 1.3mph, although average speeds were generally low prior to the intervention. At sites within the study area with higher speeds, higher average speed reductions were recorded. For the group of sites monitored with average speeds of 24 mph or more before the scheme was introduced, the average speed reduction was 6.3 mph. Casualty reduction results were only monitored for two years after implementation, however are considered positive, showing a 22% reduction in the total number of accidents compared to a 14% reduction nationally in comparable areas during the same period. No specific casualty figures for cyclists are presented.

4.5 Temporary Changes to Infrastructure

Although most infrastructure is permanent, the effects of temporary arrangements should not be overlooked. The safety of cyclists at roadworks was studied by Davies et al. (1998). Using the police recorded road casualty database they found there were 150 accidents involving cyclists at roadworks between January 1992 and December 1996. However, due to under-reporting, especially for cycle accidents involving collisions with no other vehicles, they estimated the number each year to be about 200. The authors report that reduced lane width and carriageway objects may present particular risks to cyclists at roadworks. They conclude that injuries to cyclists at roadworks are typically of higher severity than injuries sustained by cyclists not at roadworks, possibly because a high proportion of roadworks-related injuries are on A-roads with higher posted speed limits. The majority of injuries involve motorised vehicles and typically involve the motorised vehicle striking the cyclist while overtaking. There is however a higher than usual proportion of single-vehicle cycle accidents, tending to involve a carriageway object.

A survey observing cyclists and other road users at roadworks reported some atypical behaviour. Drivers were seen passing cyclists very closely, driving on the footway to pass cyclists and following very close behind cyclists. Cyclists, meanwhile, were observed riding on the footway to avoid narrow lanes or delays, and also ignoring road closure signs to gain access (Davies et al, 1998).

Another consideration is that cyclists may not always cover the desired distance during a green light phase at temporarily signalised works. Davies, et al. (1998) stated that lanes too narrow for cars to overtake cyclists may be safer than those where it is possible to overtake but the manoeuvre is unsafe. Lower speeds were also recommended along with maintaining cycle access routes which avoid adding additional distance to a cyclist's journey.

4.6 Infrastructure as a System

Most of the studies concerning infrastructure consider individual features or categories of facility. There are few convincing studies of infrastructure at the route, network, or system, level. The study of single sites frequently prevents results being reliably generalised due to low levels of activity at any one site, relatively low numbers of casualties and the unknown influence of site specific factors. These deficiencies, however, can be overcome to an extent by looking at whole districts, towns or cities.

Such an approach can reveal risk factors that are not directly related to specific infrastructure types but can relate to the urban structure and the wider context in which cycling takes place. An example of this is found in the UK, where the Road Casualties 2007 report (DfT, 2008) reported that, for cyclists, the casualty rate for the 10% most deprived areas is greater than for the 10% of the least deprived areas. Whilst the cycle casualty rate is greatest for the most deprived areas, it is people living in the least deprived areas that make the greater proportion of cycle trips (DfT, 2008).

Pucher and Buehler (2008) attempted to synthesise lessons from the Netherlands, Germany and Denmark, which they argue have successfully achieved growth in cycling and reduced casualties. They present evidence that "Both fatality and injury rates are much higher for cyclists in the USA and the UK than in Germany, Denmark and the Netherlands. Averaged over the years 2002 to 2005, the number of bicyclist fatalities per 100 million km cycled was 5.8 in the USA and 3.6 *in the UK, compared to 1.7 in Germany, 1.5 in Denmark, and 1.1 in the Netherlands."*

Pucher and Buehler (2008) argue that increasing use and improving safety have been systematically pursued in these nations since the mid 1970s via a package of policies that have reversed a preceding trend in decline of cycling and increasing cycle casualty rates. The package has included a wide range of elements:

- extensive systems of separate cycling facilities;
- junction modifications and priority traffic signals;
- traffic calming of all residential neighbourhoods;
- bike parking;
- coordination with public transport;
- traffic education and training; and
- traffic laws that protect vulnerable road users effectively.

Pucher and Buehler's (2008) level of analysis does not enable specific attribution of any one policy to positive outcomes. They do however identify segregated facilities as important and note that separate facilities' "design, quality and maintenance have continually improved".

Lynam et al (undated) compared road safety outcomes between different European nations. They note that the fatality rate for cyclists, per distance travelled, in the UK is approximately double that of Sweden and The Netherlands. In comparing a range of factors that may explain this variation they conclude that:

> *This suggests the main reason for the difference in risk rates is the difference in the environment for cyclists in the three countries. The low risk rate in Sweden and the Netherlands is almost certainly heavily influenced both by the extensive segregated cycle tracks provided and the management of traffic speeds in residential areas.*

The emphasis in these studies on segregated facilities at a system-wide level seems to contradict the equivocal evidence regarding individual segregated facilities discussed in 4.2. Possible explanations for the contradiction in the evidence include variation in the quality of provision between continental Europe and other settings; implementation within a comprehensive approach, enabling cyclists to use facilities as a system rather than as isolated features in an otherwise motor-vehicle orientated network; and willingness in continental Europe to prioritise cycles over motorised traffic, including giving legal priority over turning traffic to cyclists travelling straight ahead. The willingness to simultaneously provide both segregated facilities of high quality and traffic-calmed highways may be key to offsetting the increased risk where segregated facilities meet the highway noted in studies described above.

Until recently there have been few examples of systematic city-wide treatments intended to promote cycling and improve cycle safety. Latterly the designation and funding by DfT and Cycling England of a number of Cycling Demonstration Towns (and one City) creates the potential to evaluate system-wide approaches more thoroughly.

At the time of writing such an evaluation has been commissioned by DfT[2], although it is noted that this is after a relatively short period of implementation.

[2] http://www.dft.gov.uk/cyclingengland/cycling-cities-towns/

5 Summary and Discussion

Cycling in the UK is more than twice as risky than in Sweden and the Netherlands. This is likely to be the consequence of a range of factors, of which infrastructure is only one, however the cycling environment is identified as a key distinction by some commentators. Most of the measures identified in this review have been applied in urban, rather than rural settings. This review suggests a number of conclusions with regard to the use of infrastructure to reduce cyclists casualties, although the patchy coverage of the literature and the limited strength and depth of evidence is emphasised. The range of literature on any one type of infrastructure tends to be relatively limited, resulting in a limited depth of analysis and understanding.

Further, many of the studies are relatively small-scale, both in terms of the number of locations observed and the length of the monitoring period and often do not present data regarding the level of, and changes in, cycling activity. At many of the sites studied in the literature the number of cyclist casualties is low. This tends to render any changes in casualties statistically insignificant. There is also a tendency for studies to fail to properly control for background trends, changes in cycle use or other wider factors or to consider regression to the mean.

It is also important to acknowledge that, overseas, infrastructure may be designed differently to common UK practice. For example, typical roundabout geometry differs between the UK and Western Europe. The different legal and cultural contexts of road user behaviour, particularly those governing the priority of cyclists relative to motor vehicles, may also influence casualty outcomes associated with different types of infrastructure. A comparative analysis of the influence of different legal frameworks on cyclist casualty outcomes was beyond the scope of this paper and was not found in the literature reviewed, however it is recommended that further consideration be given to the extent to which different legal contexts interact with norms of behaviour and infrastructure design in order to offer superior casualty performance in some European nations.

Notwithstanding these limitations, the literature does allow some consideration of the effectiveness of infrastructure interventions.

Taken as a whole, the most significant infrastructure-related risk factors for cyclists in **single vehicle incidents** on highways appear to be:

- slippery road (due to weather); and
- poor or defective road surface.

For **multi-vehicle collisions** the infrastructure risk factors appear to be:

- speed limits; and
- encounters with other road users at junctions.

Note though that these are selected by police officers from a list of available factors and are not designed to be specific to cycle accidents.

Of all interventions to increase cycle safety, the strongest evidence is for the benefits resulting from reduction in motorised vehicle speed. Interventions that achieve this are also likely to result in casualty reductions for all classes of road user.

Those intending to improve cycle safety via infrastructure need to set clear objectives and be guided by those objectives in selecting the type, and design, of infrastructure. Having intermediate behavioural objectives known to be linked to reduced risk, as well as casualty reduction objectives, is recommended and recent guidance (Helman et al, 2011) is commended to practitioners.

5.1 Junctions

As with all classes of road user, junctions are particularly associated with cyclist injuries. In order to reduce the total number of cycle casualties then interventions at junctions should be a high priority, particularly in urban areas, where the majority of collisions involving cyclists take place.

Reducing the speed of traffic through junctions appears to be an effective approach to reducing cycle casualties. This can be achieved by side entry treatments, raised cycle track crossings and signalisation of large roundabouts, for all of which there is evidence of a casualty reduction benefit for cyclists. Traffic calming in general, including features that reduce traffic speed through junctions such as raised tables, is likely to be of benefit to cyclists although care should be taken with some features, such as road narrowings and the placement of speed cushions, that they do not increase conflict between cyclists and other road users. Other methods that achieve lower speeds through junctions appear likely to be beneficial although specific UK evidence is not available. Foremost among these are the restricted geometries of ‘continental’ style roundabouts where the width of circulating carriageways is lower and the deflection of vehicles away from their path is greater than typical of UK designs and, hence, the speed at which motorised vehicles can circulate is reduced as is the potential for the cyclist to be in the periphery, rather than the centre, of a driver’s vision.

With regard to junction form, 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. A study for TfL found that the signalisation of roundabouts significantly reduced cyclist casualties but this approach may not be universally applicable.

Continuing a cycle lane, particularly if emphasised by a coloured surface, through a junction appears also to reduce cycle casualties although evidence suggests that this effect is only achieved when a single lane is so marked. This would suggest that this approach is only likely to be practical where there is a particularly strong cycle desire line through a junction.

Cycle advanced stop lines (ASLs) are frequently not respected by other road users and show little safety benefit although the research in this area is particularly limited. Notwithstanding this lack of evidence, ASLs may provide a priority for cyclists and may be applicable where there are heavy flows of right-turning cyclists.

Although speed reduction may provide benefits, cyclist injuries involving HGVs at junctions were often found to take place at low speed. This suggests that relative positioning and visibility of the cyclist may be a key factor in these incidents.

A number of infrastructure interventions have been used on the continent to increase safety at junctions that are not widely used in the UK. Particular examples include cycle lane markings continued across junctions, cycle pre-signals and Trixi mirrors (mounted below signal heads to allow drivers of heavy vehicles to see cyclists at their nearside). The literature suggests that, appropriately applied, the former two approaches can have a beneficial effect on cycle casualties. The latter is currently (2010/11) being trialled by Transport for London. Wider experimentation with these approaches in the UK is recommended.

5.2 Links

On links there is little evidence in the UK that marked cycle lanes provide a safety benefit, although they may achieve other objectives. This lack of evident benefit may however represent a lack of quality and continuity in implementation. There is also extremely limited experimentation with, and no reported studies of, kerbed cycle lanes in the UK.

Providing segregated networks may reduce risk to cyclists in general although evidence suggests that the points at which segregated networks intersect with highways offer heightened risk, potentially of sufficient magnitude to offset the safety benefits of removing cyclists from contact with vehicles in other locations. This may be particularly the case if segregated networks remove cyclists from relatively low risk links but then increase their exposure at junctions. There is nevertheless a potential application for this approach and it is likely to be attractive to some users. It may be of value in rural settings where the frequency of junctions is relatively low, where required quality can be achieved and where cyclists can be protected at junctions.

The nature of the segregated network is likely to influence casualty outcomes. Footway conversion and illegal footway use are identified in the literature as risky, again as a consequence of the heightened risk where the segregated network intersects the roadway. Analysis of contributory factors attributed to cyclists in police STATS19 records from 2005-07 identify that the second most commonly attributed factor, accounting for 17% of all fatal injuries, and 34% among under 16s, was 'entering road from pavement'.

Segregated networks away from the highway may reduce the typical severity of casualties however the data collected nationally does not allow this to be determined reliably. In any case the vulnerability of cyclists to poor surfaces suggests that the design and maintenance of such facilities is important. The detailed design of such facilities is likely to be critical to their performance. This is particularly the case for junctions between cycle facilities and carriageways for general traffic. It is suggested that the positive performance of some such facilities in continental settings may represent a qualitative difference in design and a willingness to slow motorised vehicles with physical measures at the points where the two networks intersect.

5.3 Systemic Approaches

The evidence is strong that reducing the general speed of motorised traffic confers a safety benefit for cyclists. This may be achieved through placemaking methods, physical traffic calming and, possibly, the wider use of 20mph speed limits.

In Western Europe, network wide segregated facilities supported by traffic calming on the highway network appears to offer an effective system-wide approach. Piecemeal implementation of such an approach however is unlikely to be satisfactory and careful consideration needs to be given as to the best sequence in which to introduce measures. Achieving a functional network for cyclists in urban areas based on these continental principles would require:

- sustained investment over decades
- a willingness to prioritise cycle traffic
- A multi-faceted approach seeking to increase cycle safety and cycle use together
- A focus on achieving high-quality outcomes.

In addition to design, different legal conventions, particularly governing priority at junctions, may influence casualty outcomes in continental countries as opposed to the UK. Notwithstanding this, it is acknowledged in nations such as the Netherlands where this form of facility is common that managing conflict between cyclists and motorised vehicles at intersections is safety critical. Separate facilities that do not frequently intersect the general highway network will not suffer from the same drawback, however they are only likely to be achievable in rural settings.

It should be noted that most of the evidence presented has been gathered from urban studies. Cycle safety benefits might also be realised from motor vehicle speed reductions in rural settings. However, the options to achieve that speed reduction might be substantially more limited on rural roads. Localised exceptions to this could be spot treatments in specific locations such as villages.

In some situations, the type of infrastructure selected for a given site may not meet cyclists' needs. Where infrastructure does not meet the needs of cyclists, they may behave in ways that could increase their risk, such as illegally using footways not designed for cycling (Gibbard, 2004). This failure is sufficiently widespread that methodologies such as Cycle Audit and Cycle Review (IHT, 1998) and Non-motorised User Audit, Highways Agency, (2005) have been devised. These prompt designers of highway schemes to thoroughly consider the requirements of cyclists. The requirements for such procedures are underlined by Christmas et al’s (2010) finding from qualitative research with cyclists, who commented that there were instances of cycle facilities that:

- ended suddenly, leaving the cyclist having to rejoin traffic;
- were punctuated by drains and manhole covers, or poorly maintained;
- required the cyclist to stop frequently, e.g. a pavement cycle track crossing side roads; and
- were impinged on by traffic, or used to park cars.

Other recent documents such as Manual for Streets 'MfS1' (DfT, 2007) and Manual for Streets 2: Wider Applications of the Principles 'MfS 2' (CIHT, 2010) seek to demonstrate the benefits that derive from good highway design that in particular assigns a higher priority to pedestrians and cyclists.

Finally, there is a lack of a solid evidence base around both common and innovative methods of increasing cycle safety.

Monitoring and evaluation of common methods appears limited and is compounded by a lack of exposure data for cyclists. More frequent monitoring of scheme outcomes, including their effects on intermediate, behavioural outcomes, is commended, as is more systematic collection of exposure data.

There are some approaches to improving cycle safety that are in use in Europe but which are rarely used and have not been assessed in the UK. The local authority survey described in this review identified the relatively limited repertoire of infrastructure interventions in use in the UK, with no examples given, at the time, of approaches such as general exemptions from one-way restrictions, false one-way streets etc. Given the limitations of many existing types and approaches to infrastructure, more innovation and experimentation, informed by much more appropriate monitoring and evaluation, is strongly recommended.

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Appendix A - Literature Review and robustness

The Literature Review undertaken by MVA Consultancy consisted of the following four phases:

- Searching of published and unpublished literature;
- Grading of literature;
- Analysis of literature; and
- Reporting.

The second stage, grading, was particularly important to help identify papers and articles that were of sufficiently high quality for further, more detailed analysis.

The grading of literature used a 'filtering' methodology to provide a consistent and quick means of selecting the search results based on three criteria:

- Relevance;
- Quality; and
- Timeliness.

Performance against each criterion was assessed used a three-level rating – high, medium, and low. Based on the combined ratings for relevance, quality, and timeliness a decision was made whether to investigate the piece of research further. This ensured that there was a consistent and transparent process for selecting articles.

Relevance

- High – highly and directly relevant to cycle safety with primary data referred to in the abstract text – essential reading;
- Medium – generally relevant to cycle safety – only to be followed-up further if time permits; and
- Low – incidental connection only to cycle safety – do not follow-up further.

Quality

- High – from an internationally recognised and peer-reviewed source;
- Medium – from an academic journal or book (unknown / uncertain review process) or from a conference/symposium; and
- Low – from conference proceedings (general, open-to-all events), general discussion papers etc.

Timeliness

- High – published in 2005 onwards;
- Medium – published in any year between 1999 and 2004 inclusive; and
- Low – published earlier than 1999.

All the articles referenced in this Report met the required robustness criteria:

- medium or high relevance;
- medium or high quality; and

- in the majority of cases, medium of high timeliness.

Given the relatively limited range of articles covering infrastructure, articles rated as 'low' for timeliness were included in order to provide as much information as possible. A summary of the assessment against the three criteria of each cited article or report is provided in **Appendix B**.

Appendix B - Assessment of relevance, quality and timeliness of referenced articles

Reference	Timeliness	Relevance	Quality
Allen, D.L. Bygrave, S. & Harper, H. (2007)	High	Medium	High
Atkins, (2005)	High	High	High
Aultman-Hall, L and Hall, FL (1998)	Low	High	High
Aultman-Hall, L and Kaltenecker, MG (1999)	Medium	High	High
Basford, L. & Reid, S. (2002)	Medium	Medium	High
Christmas et al. (2010)	High	High	Medium
CIHT (2010)	High	Medium	Medium
Coates, N (1999)	Medium	High	High
Cyclists' Touring Club (CTC) (2000)	Medium	Medium	High
Daniels S, Nuyts, E, Wets, G, (2008)	High	High	High
Davies, D.G. Ryley, T.J. Coe, G.A. and Guthrie, N.L. (1998)	Medium	Medium	Medium
DfT (2007)	High	Medium	High
DfT (2008)	High	High	Medium
DfT (2008b)	High	High	Medium
Faber Maunsell (2005)	High	High	High
Fernandez de Cieza, A.O. et al. (1999)	Medium	High	High
Franklin, J. (1999)	Medium	Medium	High
Franklin, J. (2002)	Medium	High	Medium
Garrard, J, Rose, G, Lo, SK (2008)	Medium	High	High
Garder, P. (1994)	Low	High	High
Garder, P. Leden, L. & Pulkkinen, U. (1998)	Low	High	High
Gibbard, A, Reid, S, Mitchell J, Lawton B, Brown E and Harper H (2004)	High	High	Medium
Guthrie, N, Davies, D.G. & Gardner, G. (2001)	Medium	Medium	High
Hass-Klau, C. (1991)	Low	Medium	High
Helman, S. et al. (2011)	High	Medium	Medium
Hels, T. & Orozova-Bekkevold, I. (2007)	High	High	High
Héran F, Asencio S. Giess Y. CADR, (2006)	High	High	Medium
Highways Agency (2005)	High	Medium	High
Hopkinson, P. & Wardman, M. (1996)	Low	Medium	High
IHT (2008)	High	Medium	High
Jacobson, G.A. et al., (1998)	Low	High	High
Jensen, S.U. (2008)	High	Medium	High
Jonsson, L., (2007)	High	High	High

High Timeliness - published in 2005 onwards
Medium Timeliness - published in any year between 1999 and 2004 inclusive
Low Timeliness - published earlier than 1999

High Relevance - highly and directly relevant to cycle safety with primary data referred to in abstract - essential reading
Medium Relevance - generally relevant to cycle safety - only to be followed-up further if time permits
Low Relevance - minor / incidental connection only to cycle safety - do not follow-up further

High Quality - from an internationally recognised (and therefore peer-reviewed) source
Medium Quality - from an academic journal or book (unknown / uncertain review process) or from a conference/symposium (internat
Low Quality - from conference proceedings (general, open-to-all events), general discussion papers etc

Reference	Timeliness	Relevance	Quality
Kim, J.K. Kim, S. Ulfarsson, G.F. & Porrello, L.A. (2007)	High	High	High
Knowles J, Reid S, Cuerden R, Savill T, Adams S, and Tight M (2009)	High	High	Medium
Knowles J, Adams S, Cuerden R, Savill T, Reid S, Tight M (2009b)	High	High	Medium
Lawton, B. Webb, P.J. Wall, G.T. & Davies, D.G. (2001)	Medium	Medium	Medium
Layfield, R.E. (1994)	Low	Medium	High
Leden, L. (2006)	High	High	High
McCarthy, M. & Gilbert, K. (1996)	Low	High	High
Mcclintock, H. Jacobsen, H.J. &Siboni, L. (1992)	Low	Medium	High
Meuleners, L. Gavin, A. Cercarelli, L. & Hendrie, D., (2003)	Medium	High	High
Morgan, J.M. (1995)	Low	Medium	Medium
Moritz (1998)	Low	High	High
Parkin, J and Meyers, C, (2009)	High	High	High
Pedler, A. & Davies, D.G. (2000)	Medium	High	High
Petersson, E. & Schelp, L., (1997)	Low	High	High
Pucher, J and Buehler, R, (2008)	High	High	High
Rasanen, M. Koivisto, I. & Summala, H., (1999)	Medium	High	High
Rasanen, M. & Summala, H., (1998)	Low	High	High
Reid S and Guthrie N (2004)	Medium	Medium	High
Richards, D. (2010)	High	Medium	Medium
Robinson, D.L. (1995)	Low	High	Medium
Schoon, C. and J. Van Minnen (1994)	Low	Medium	High
Stone, M. & Broughton, J. (2003)	Medium	High	Medium
Stutts, J.C. Williamson, J.E. Whitley, T. & Sheldon, F.C. (1990)	Low	High	High
Taylor, S.B. & Halliday, M.E. (1997)	Low	Medium	High
Transport Research Laboratory, (2005)	High	High	High
Travers Morgan Pty Ltd, (1987)	Low	Medium	High
Turner, S and Binder, S (2009)	High	High	High
Turner, S.A. & Roozenburg, A.P., (2006)	High	High	High
Vandebona, U and Kiyota, M (2001)	Medium	Medium	High
Walker, I. (2007)	High	Medium	High
Webster, D.C. & Layfield, R.E. (2005)	High	Medium	High
Williams, M.C. (1989)	Low	Medium	High
York, I. et al. (2007)	High	High	Medium

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Infrastructure and cyclist safety

This literature review considers the role of infrastructure in relation to the safety of cyclists and their interaction with other road users. It was undertaken as part of the wider research programme, Road User Safety and Cycling, being led by TRL. The paper identifies the influence of infrastructure on intermediate, behavioural, outcomes which may influence casualty risk, such as the speed of motorised traffic, cyclist route choice and manoeuvres etc. Of all interventions to increase cycle safety, the strongest evidence is for the benefits resulting from reduction in the general speed of motorised traffic. This may be achieved through a variety of methods including physical traffic calming; urban design that changes the appearance and pedestrian use of a street; and, possibly, the wider use of 20mph speed limits. The literature review also identifies the potential benefits of treating junctions, particularly interventions that slow the speed of motorised traffic through them. The review identifies the potential benefits of segregated networks for cyclists but notes evidence that cyclists may be exposed to heightened risk where cycle networks intersect the general highway network. The review also identifies a number of techniques to improve cyclist safety that are in use in overseas but which have not been commonly applied in the UK. Given the limitations of many existing types and approaches to infrastructure, more innovation and experimentation, supported by appropriate monitoring, is recommended.

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TRL
Crowthorne House, Nine Mile Ride
Wokingham, Berkshire RG40 3GA
United Kingdom

T: +44 (0) 1344 773131
F: +44 (0) 1344 770356
E: enquiries@trl.co.uk
W: www.trl.co.uk

Published by

IHS
Willoughby Road, Bracknell
Berkshire RG12 8FB
United Kingdom

T: +44 (0) 1344 328038
F: +44 (0) 1344 328005
E: trl@ihs.com
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Price code:3X

ISSN 0968-4093

ISBN 978-1-84608-989-3

9 781846 089893

PPR580