ANNEX XI
to SWOV report
Safety effects of road design standards
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Bicycles facilities at intersections

A review of the guidelines in Denmark, The Netherlands, United Kingdom, and Germany

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Notice to the reader

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Annex I: Road classification and categorization
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Annex II: Assumptions used in road design
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Annex III: Methods for investigating the relationship between accidents, road user behaviour and road design standards
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Annex IV: International organizations and road design standards
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Annex V: National road design standards
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Annex X: "Bicycles at intersections" in the Danish Road Standards
L. Herrstedt; Danish Road Directorate, Copenhagen, Denmark

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M.P. Hagenzieker; SWOV Institute for Road Safety Research, Leidschendam, The Netherlands

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Summary

This report provides an overview of standards relating to 'Bicycle facilities at intersections' as could be obtained for the following EC-countries: Denmark, the Netherlands, United Kingdom, and Germany. Standards for bicycle facilities are reviewed for intersections located inside built-up areas as well as for those located outside built-up areas. Attention is paid to bicycle facilities at different types of intersections, and takes into account factors such as their physical lay-out (with or without traffic lights; roundabouts etc.), and priority ruling. A summary of the standards is given for each country under consideration , as well as a bibliography of the documents that have been used.

The various standards differ not only between, but also within countries in several respects, including their status - whether they are compulsory, or non-compulsory guidelines or recommendations. Design standards for specific bicycle facilities, or 'solutions', at intersections, as reviewed in this report, are generally non-compulsory guidelines and recommendations. Therefore, the terms 'guidelines' and 'recommendations' describe their status better than the term 'standard' might imply.

Also, the criteria that have been used for drawing up the various standards, guidelines, and recommendations are discussed for each country, with special emphasis on the role of road safety considerations as the underlying criterion. Road safety as a criterion for establishing guidelines and recommendations for bicycle facilities at intersections, is considered 'important' in all countries. However, safety has to compete with other criteria such as traffic flow and comfort, and, in general, no strong safety evidence is to be found in the guidelines themselves.

Finally, some common principles and 'solutions' are summarized. For instance, creating good sight conditions and the separation of biyclists from other traffic, either physically or visually, are mentioned in all guidelines as being an important principle or (safety) criterion.

1. General introduction

Individual EC-countries usually have specific road standards, guidelines and/or recommendations. To date, no overview has been available regarding the various standards for bicycle facilities at intersections which exist in EC-countries. This report is a first attempt to provide such an overview and has turned out to be not an easy task. Besides the fact that standards have usually been formulated only in the language of the specific country concerned, and terminology is not always consistent between countries, even within countries these standards are not usually put together in one single document; instead they are to be found as chapters or paragraphs in various documents regarding road standards in general. Getting hold of the relevant publications was a difficult job in itself. For only four countries specific documentation on bicycle facilities at intersections could be obtained.

The report provides an overview of standards relating to 'Bicycle facilities at intersections' as could be obtained for the following EC-countries: Denmark (Chapter 2), the Netherlands (Chapter 3), Great-Britain (Chapter 4), and Germany (Chapter 5). Standards for bicycle facilities are discussed for intersections located inside built-up areas as well as for those located outside built-up areas. Attention is paid to bicycle facilities at different types of intersections, especially in relation to their physical lay-out (with or without traffic lights; roundabouts etc.). Intersections between two separate cycle-paths with their own alignment, and intersections between carriageways and such cycle-paths have been left out in this report. This has been done even though such intersections are usually taken into account in the various guidelines. However, these types of intersection do not occur very often, and we have chosen to discuss the more 'common' types of intersection. The conflicts between cyclists and other cyclists, cyclist and mopeds, and cyclists and pedestrians are excluded from this report. A summary of the standards is given for each country under consideration , as well as a bibliography of the documents that have been used.

The chapter on Denmark is a shortened version of the report "Bicycles at intersections in the Danish Road Standards" by L. Herrstedt (1993). Some elements of Herrstedt's report that do not specifically refer to bicycle facilities at intersections were left out. In addition, terminology has been adjusted to correspond with the terminology that is used in the other chapters of this report (see par. 1.1).

The various standards differ not only between, but also within countries in several respects, including their status - whether they are compulsory, or non-compulsory guidelines or recommendations. In each chapter the status of the various 'standards' (i.e. including guidelines and recommendations) which have been used for this report is discussed. In addition, the criteria that have been used for drawing up the various standards, guidelines, and recommendations are discussed for each country, with special emphasis on the role of road safety considerations as the underlying criterion.

Finally, in chapter 6 a comparison is made between the standards of the various countries, and the conclusions are summarized.

1.1. Terminology

In general, terms referring to specific bicycle facilities and 'solutions' at intersections will be explained in the text the first time they are mentioned. In most cases, a schematic drawing is also provided which illustrates the facility under consideration. In this paragraph some more common terms will be explained, partly because they are not further described in the various chapters, and partly because the usage of terms in the guidelines often varies between countries. We have chosen to use these more common terms in a consistent manner throughout this report according to the definitions described below.

Cycle tracks, lanes, paths, and routes

Throughout this report the term *cycle track* is used when this cycle facility is separated from the carriageway by a narrow dividing verge or by kerbstones ('physical separation'). The term carriageway refers to a road or part of a road to which vehicles - including bicycles in case no specific (compulsory) bicycle tracks are present - have access. The term *cycle lane* refers to a part of the carriageway which is meant to be used by bicyclists, and is indicated by markings or painted lines on the road surface ('visual separation'). In some countries, for instance in The Netherlands, within these types of cycle facilities a distinction is made between on the one hand voluntary or recommended use of them by bicyclists, and compulsory usage on the other hand. Whenever it is considered relevant this distinction has been mentioned in the text. The term *cycle path* is only used for separate cycle tracks with their own alignment (away from roads). The term *cycle route* is used as the general word for cycle paths, for cycle tracks, for cycle lanes, and for roads without any cycle facility that serve as a link in the bicycle network.

Bent-out cycle tracks

A common facility for bicycles at intersections which is described in the various guidelines, is a bent-out cycle track. This term refers to a cycle track that is led from the carriageway for a certain distance before and after an intersection. In Denmark the term 'staggered cycle track' is used for this facility, whereas in Germany and the Netherlands the term 'bent-out cycle track' is used. Throughout this report the term 'bent-out cycle track' is used for this facility.

Intersections, junctions, and crossings

Throughout this report the terms *intersection* and *junction* are used interchangeably. In general, however, 'junctions' usually refer to relatively large types of intersection. The term *crossing* is used for that part of the carriageway or intersection used by bicyclists for crossing.

2. Denmark

2.1. The philosophy behind guidelines and recommendations

The philosophy behind the Danish road standards for urban areas is based on a fundamental *road* and *speed classification system*, in which traffic safety is of prime importance (see Herrstedt, 1993; Janssen, 1994 for a more detailed description of road classification). The parts that apply to bicyclists will be summarized here.

Two route classes
The light road users' traffic network can be divided into two classes, namely

- main routes and
- local routes.

The light road users' main traffic network as defined in the municipal plan's main traffic structure, serves the main pedestrian, bicycle, and moped traffic in a given area.

In planning the route network for light road users the following items should be considered:

- safety and feeling of security
- accessibility
- direct routes
- connection
- clearness of layout
- environmental experiences, and
- climatic conditions.

Traffic safety is the most essential of these considerations. The others, however, are important in their own right, and contribute to attracting traffic to the network for light road users, thereby contributing to traffic safety.

We will concentrate on bicycle facilities here. In this regard, the distinction between three main types of facilities is important (see Figure 2.1.1):

- separate cycle paths (away from roads)
- cycle tracks along roads
- main cycle routes using local roads.

Safety and security
Safety is best ensured by constructing separate cycle paths. However, in existing urban areas, it will often be impossible to establish separate cycle paths that are placed and aligned so that they will be properly used.

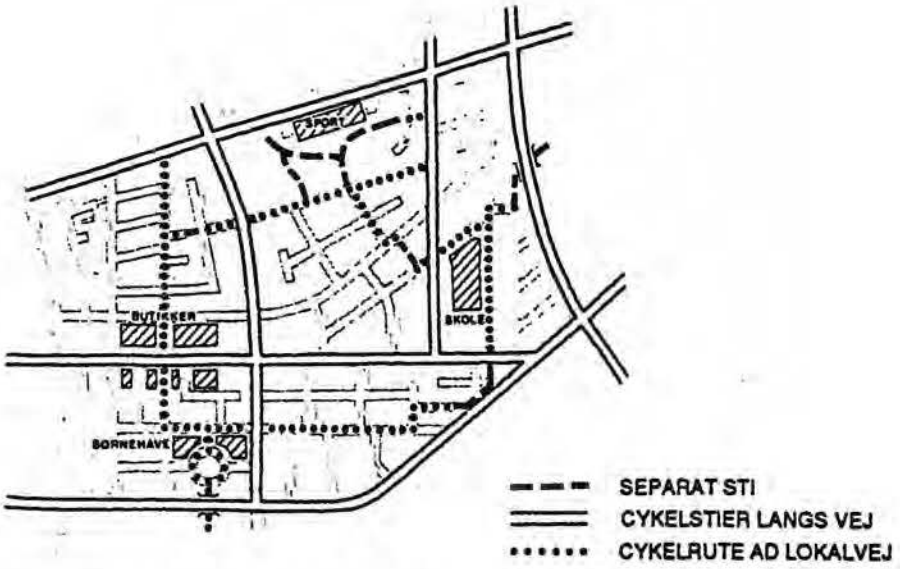


Figure 2.1.1. Route network for light road users.

Therefore, where bicyclists are forced to share the ordinary road system, they should be protected by:

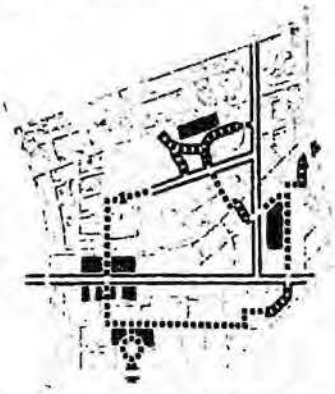
- construction of cycle tracks along busy roads;
- adjustment of car speed;
- careful securing of spots where they cross motor traffic; and
- securing of spots where there is a conflict with other light road users, e.g. at bus stops on roads with cycle tracks.

Not only safety but also the feeling of security should be a main objective in the planning of the route network for light road users. One should remember in this situation that the feeling of insecurity may be caused both by the risk of traffic accidents and by the fear of various forms of criminal action. Most importantly, separate cycle paths should therefore be designed very carefully and special attention should be paid to unrestricted visibility, lighting and alignment along trafficked routes.

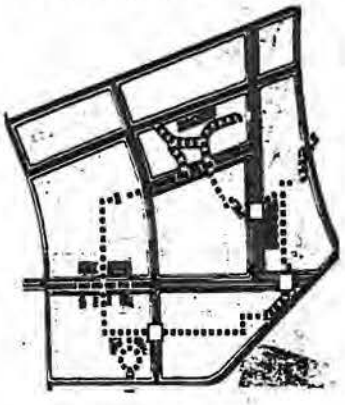
Identification of main intersections and crossing points

The combination of the functional classification and speed classification of the road network together with the description of the light road users' main routes lead to the identification of points of intersection.

The classified road network.



The light road users' main traffic network.



Intersections and crossing points.

2.2. Status of standards for bicycle facilities

Stating prescriptive standards for existing - and new - areas is difficult because the physical reality will often provide only limited possibilities for the application of such standards. Therefore all the instructions in the Danish road standards are, in general, non-compulsory, i.e. recommended guidelines which may be relaxed, if appropriate.

Some of the instructions concern subjects that are also described in other road standards and associated provisions, such as "Road Standards for Road Marking" and "Road Standards for Traffic Lights", and the Ministry of Justice's Order and Circular concerning the marking of roads. *Wherever an instruction is stated in these road standards as compulsory requirement this status is explicitly mentioned (and marked on a dark background) in this chapter.* All other instructions are non-compulsory guidelines.

2.3. Bicycle facilities at intersections inside built-up areas

2.3.1. *The role of road safety considerations in the Danish standards for bicycle facilities*

The whole philosophy behind the Danish road standards inside built-up areas (see par. 2.1), and the criteria mentioned in this and following paragraphs are based upon traffic safety considerations. So, consideration for road safety must be a primary condition when planning a new intersection, when choosing the type of intersection and in the detailed design of an intersection and its surroundings. Driving over an intersection usually involves complicated manoeuvres, in which road users must perform many evaluations, e.g., of the position of other road users, their speeds, etc. It is crucial for road safety that road users have sufficient time to understand their situation and adapt their speed accordingly.

In urban areas and when reconstructing roads, the design of the intersections will normally be of decisive significance for the permitted speed. It may therefore be necessary to emphasize the desired reference speed with physical and optical measures at the intersections.

Apart from general requirements for intersections with respect to car traffic, special care must be given to light road users, i.e. pedestrians, cyclists and moped riders. This is partly because the accident risks of these road users are particularly high and the degreee of injury is usually greater. In addition, their style of travelling is less predictable than that of vehicle traffic and even small inconveniences, in the form of detours or suchlike, can cause inappropriate bicyclist behaviour at intersections.

In the Road standards for facilities inside built-up areas, a number of general requirements based on safety considerations are enumerated, i.e. the planning, design, marking and signing of intersections. It will often be difficult to satisfy these requirements in urban areas. For this reason, it can often be necessary to apply the requirements "in reverse", i.e. by removing intersections and junctions that are unsuitably located or that cannot be given a reasonable form.

2.3.2. *Types of intersections*

Figure 2.3.1 shows a guide to the combinations of the main types of intersections and reference speeds.

	Speed class			
Type of intersection	Very low (10-20 km/h)	Low (30-40 km/h)	Medium (50-60 km/h)	High (70-80 km/h)
Intersection controlled by traffic lights		X	X	(X)
Priority +-junction not controlled by traffic lights		X	X	(X)
Priority T-junction not controlled by traffic lights		X	X	X
Exit construction from side road	X	X	X	(X)
Roundabout		X	X	X
Non-priority crossing	X	X		

Figure 2.3.1. Combinations of type of intersection and the reference speed of the major road. The combinations marked with "(X)" are not to be recommended and should therefore not be used in new constructions.

2.3.3. *Traffic lights*

Traffic lights for the sake of cyclists

Traffic lights can be established for the sake of cyclists where:

- there is a special risk of accident;
- there are many cyclists and/or pedestrians;
- the total average hourly traffic of pedestrians and cyclists who cross the road in the four peak traffic hours - not necessarily consecutive - exceeds 200, while the total average hourly traffic driving on the road they must cross exceeds 600 in the same period. Where there are traffic islands the latter figure can be increased to 1000 vehicles. Close to schools, old-peoples homes, etc., special circumstances may apply (large number of vulnerable road users, but for short periods).

In this context, a warning is appropriate against excessive reliance on the safety-promoting effects of traffic lights. In cases where many accidents occur between motorists due to crossing and turning, traffic lights can reduce the accident count but they will very often increase the number of rear end collisions, accidents when turning left in front of traffic from the opposite direction, and accidents between light road users and turning traffic.

Cyclist traffic lights
Cyclist traffic lights are an auxiliary aid, which is significant only to cyclists and moped riders, for whom they replace normal traffic lights.

Cyclist traffic lights may only be used where there is a cycle track and then only if the signalling for cyclists differs from the signalling for vehicles, e.g., if cyclists are given an early green light.

Cyclist traffic lights should be erected at the stopline or, where circumstances make it desirable and where there is absolutely no doubt about the stopping point, within 5 m of the stopline. They should be located to the right of any main traffic lights controlling the same direction. Their location should be such that it is impossible to confuse the two sets of traffic lights.

Apart from the above, the cyclist traffic lights can be repeated as directly as possible in the field of view of the waiting cyclists.

Cycle detectors
Cycle detectors should operate automatically.
However, where special circumstances apply, manually-operated detectors (push-buttons) can be used. In such cases, they are recommended to have incorporated indicator lamps that catch the eye of cyclists and that obviously apply to the relevant stream of cyclists.

Traffic lights. Safety periods
The safety periods between opposing sets of traffic lights should be long enough to ensure a reasonable degree of safety. On the other hand, excessive safety periods can easily be considered unacceptable and can therefore diminish the respect that road users have for the traffic lights.

As a rule, the safety period between two arbitrary opposing sets of traffic lights are set so that the road users just avoid each other, when the parameters (dimensioning values) of the table on the next page are used.

When all potential for conflict has been investigated, the safety periods are determined on the basis of the most dangerous situations, i.e. those that demand the longest safety period.

Speed measurements on cyclists at signalized urban intersections have shown that the speed of "the latest cyclist towards car" on 5 m/sec is too high (6, 12). From the measurements (12) it is suggested, for safety reasons, to reduce this basical speed value to 3.5 m/sec).

The recommended values on "Passage time after green" is based on 20 year old information on road user behaviour and must be reconsidered.

	Earliest road user		Latest road user	
Guiding dimensioning values for calculation of safety period	Speed V^s	Passage time before green	Speed V^r	Passage time after green
Vehicle (8 m long) (0 m with respect to pedestrians)	13 m/s	0 s	13 m/s	3 s
Bicycles with respect to drivers	8 m/s	0 s	5 m/s	2 s
Bicycles with respect to pedestrians	10 m/s	0 s	5.5 m/s	0 s
Pedestrians	2.5 m/s	0 s	1.5 m/s	0 s

Figure 2.3.2. Note: The figures in the table must only be considered as dimensioning values, which experience shows usually give reasonable safety periods, regardless of whether or not they completely reflect reality. (6)

2.3.4. *Individual elements*

Car lanes

At intersections without traffic lights

Right-turn lanes for vehicles are normally only recommended on primary roads where there is heavy vehicle traffic and a cycle track. Right-turn lanes remove the pressure on drivers turning right to turn too quickly, thereby possibly colliding with cyclists.
Omitting to establish a right filter lane can have the effect of slowing traffic.

Roads at roundabouts should only have a single access lane and a single exit lane to ensure the safety and security of light road users.

The widths of access lanes where bicycle traffic is low should normally be kept within the intervals as shown in Fig. 2.3.3. In cases where cyclists use the straight-ahead lanes extensively their width should be increased by 0.75 m, on roads with speed class "Medium" or, exceptionally, "High".

The reason for the addional 0.75 m to the lanewidth in cases with high volumes of cycle traffic is that forcing of cyclists, resulting in safety and security problems, is assumed to be avoided.

Lane	Speed class			
	Very low (10-20 km/h)	Low (30-40 km/h)	Medium (50-60 km/h)	High (70-80 km/h)
Straight ahead lane at intersection with traffic lights or on primary road at priority intersection	2.50*)-2.75	2.75-3.00	3 00-3.25	3 50
Pure turning lane at intersection with traffic lights or left-turn lane on primary road at priority crossing		2.50*)-3.00		
Access lane on secondary road at priority crossing		2.50*)-3.50		

Figure 2.3.3. Lane widths (m), traffic lanes with only insignificant cycle traffic.

*) A lane width of 2.50 m should only be used where vehicles with a width of more than 2.20 m occur only rarely. Otherwise, the lane width should be at least 2.75 m. The marking of lanes narrower that 2.75 m requires dispensation from the compulsory requirements in Road Standards governing lane marking and from Circulars governing road marking.

Cycle tracks

Intersections with cycle tracks on one or both roads should be given appropriate facilities for cyclists, according to the following principles.

When determining the routes of cyclists at intersections, detours should be avoided as far as possible and short cuts should be made difficult or prevented - but without reducing the view.

Cycle tracks and cycle lanes should only be conducted round the corners of intersections where cyclists never turn left or ride straight ahead.

At intersections with traffic lights, cycle tracks should be located immediately adjacent to the motor vehicle lane in the access area, partly to limit the total area of the intersection and partly to enable drivers to see the cycle track in their right-hand mirrors.

Cycle tracks and lanes can be continued to the stopline. However, this can diminish safety conditions, especially for moped riders.

Instead, the cycle track or lane can be interrupted at some distance from the stopline, which makes it possible for cyclists, moped riders and right-turning vehicles to mingle in a lane marked with right-turn arrows. However, if cycle traffic is to be controlled independently, it is necessary to bring the cyclists up to the stopline.

The general experiences from Danish and Nordic research during the last years indicate that the safest solution in signalized urban intersections is to let cyclists approach the intersection close enough to the cars moving in the same direction so that the two road users can easily observe each other.

*This can take place on a shared right turn lane (although cyclists feel much less safe here), on a cycle lane (painted) or on a cycle track, on which special attention-enhancing and separation securing arrangements have been installed. (**9, 10, 11**)*

*The ongoing Danish research project on "safety of cyclists in urban areas" managed by Danish Road Directorate include research on these last mentioned arrangements. (**10**)*

Conversely, inherently unsafe designs are intersection layouts such as a cycle track which runs along the carriageway at a distance of about 3 metres and at that distance from the carriageway crosses an intersection , and the usual Danish curbed cycle track that continues right to the stopline. **(9, 11)**

At intersections without traffic lights, a cycle track can be interrupted or continue through the intersection (junction of side road with exit construction) and, in the latter case, it can also be relocated closer to the secondary road (bent-out cycle track); see Figs. 2.3.4, 2.3.5 and 2.3.6. There is no basis for choosing between the three principles out of consideration for the conditions of cyclists. In the case of moped riders, an interrupted cycle track is safest. Where a cycle track crosses through an intersection (Fig. 2.3.5), it should be immediately adjacent to the motor vehicle lane, so that the drivers of trucks can see in their right-hand mirrors cyclists approaching from behind. Where a cycle track is bent-out (Fig. 2.3.6), the degree of bending out should be so great that cyclists can be observed through the side windows of vehicles turning right and so that a private car can wait for the cycle traffic, without the driver feeling compelled to start too soon by vehicles driving straight ahead. Nevertheless, the cycle track should be considered as an integral part of the crossing. Bending out by between five and seven m will normally serve this purpose.

At roundabouts, cycle tracks are recommended to be located immediately adjacent to the motor vehicle lane. Along the access and exit lanes, the cycle tracks are recommended to extend right up to the circulation area, so that cyclists are not crowded by right-turning vehicles.

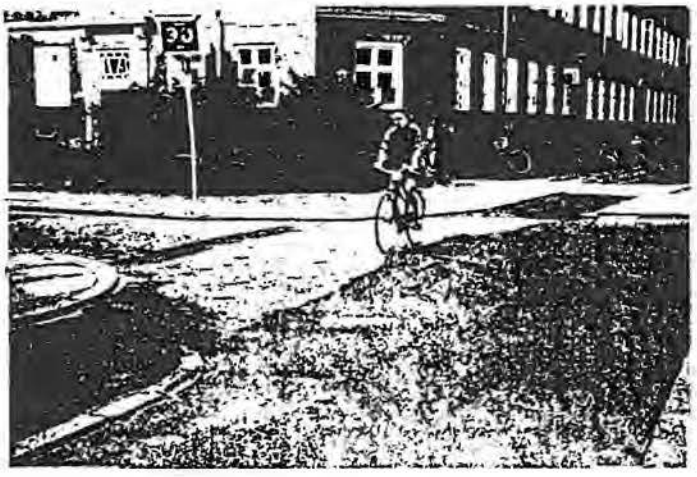


Figure 2.3.4 Interrupted cycle track.

Figure 2.3.5 Cycle track continuous through intersection.

Figure 2.3.6 Bent-out cycle track.

Cyclists' crossings

Where a cycle track is interrupted and where it is considered that there is a need to draw attention to conflicts between cyclists and motorists, the cyclist crossing is recommended to be demarcated by a broad broken line, possibly supplemented with cycle symbols, cf Statutory Orders and Circulars on marking. So, it is voluntary to establish cyclist crossings, but when it concerns markings with regard to cyclist crossings then it is compulsory to do the marking as described in the following text:

S 21

Statutory order on marking of roads, Paragraph 48 S 21 "Cyclist crossings"
Areas at intersections that indicate that cyclists and moped riders must use the relevant part of the road. Such areas are marked with a broken broad line, with line sections and breaks of equal length, or with a blue surface. V 21 "Cycle symbol" shall always be marked in the area.

Circular on marking of roads, Paragraph 48, S21 "Cyclist crossings"
185. Cycle areas shall be marked as "cyclist crossing" where it is considered that there is a need to draw attention to conflicts between cyclists and motorists.

Cyclist crossings must not be established for cyclists and moped riders that must give way or must turn right.

Cyclist crossings must be marked with broad broken lines extending to the separation between opposing traffic lanes of the road that intersects. If the lane width of the road that crosses is less than 5.5 m, the line should extend right through the crossing. Only the left-hand edge of the cyclist overpass should be marked. The line shall be marked with 50-cm long, 30-cm broad markings.

V 21

V 21 "Cycle symbol" shall always be marked in the area.

At more complex intersections, the line can pass right through the intersection and the right-hand edge of the cyclist crossing can be marked with a broken broad line. Where the right-hand edge of the cyclist crossing is bounded by another marking, eg a pedestrian area or give-way line, the broken line at the right-hand edge of the cycle area can be omitted.

186. At more complex intersections, the entire cyclist crossing can be marked in blue as a supplement to, or replacement for, broad broken lines. This type of marking should be used where the risk of accident to cyclists and moped riders is especially great, e.g. where such crossings extend bi-directionally over a side road or bi-directionally through an intersection controlled by traffic lights, or where turning of cars in the same direction across the cycle crossing is permitted from more than one lane, or where it is not possible to gain a reasonably free sight between the motor vehicle lanes and cycle track before the intersection. Blue is the only colour used for marking of cycle crossings at intersections.

If a cyclist crossing is not marked in blue it has the same colour as the surface of the vehicle lane. The cycle track surface can be used in the cyclist crossing if a long, contiguous route system has special surfacing, such as red, to emphasize the structure of the route system.

If the cycle track surface extends through the crossing, a cyclist crossing shall be marked with a broken broad line and cycle symbol.

Bi-directional cycle tracks
Where a bi-directional cycle track crosses a traffic road, the crossing should either be controlled by traffic lights or, possibly, a roundabout should be constructed.

Where it crosses a local road at an intersection without traffic lights, the cycle track can cross the road at the pavement level.

Bi-directional cycle tracks shall always extend right up to the crossing.

It will normally be advantageous from the standpoint of the safety of cyclists if right-turn lanes are constructed at the intersection.
The strip separating the motor vehicle lane and bi-directional cycle track shall be not less than 1 m and not more than 6 m broad. However, if there is a right-turn lane, the width of the separating strip can be reduced to 0.5 m or it can be replaced by a raised kerb. Where vehicles turning right and cyclists travelling straight ahead share a common period of the green light, the breadth of the strip must not exceed 0.5 m.

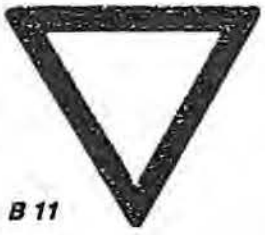
The reason for the value of 0.5 m width is that right turning car drivers and straight ahead going cyclists approaching the intersection will drive so close to each other that they can easily observe each other and thereby avoid accidents in signalized intersections (19, 20).

A 21

A circular on road marking contains the following on cycle tracks at crossings.

The bi-directional cycle track shall be marked with a broken narrow line, with line sections and breaks of equal length. The line shall extend across side roads and driveways.

At side roads, both sides of the line shall be marked with V 21 "Cycle symbol". Sign B 11 "Give way unconditionally" shall be erected at side roads and exits from which road users cross a bi-directional cycle track. However, this does not apply to exits from individual properties that are not visited by many road users who lack a knowledge of the local area. The sign shall also display the UB 11.2 supplementary sign.



B 11

If sign B 13 "Stop" is present, supplementary sign UB 11.2 shall be placed below it.

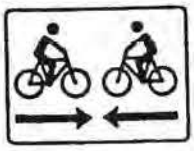
Where cyclists and moped riders cross the vehicle lane at the start or end of a bi-directional cycle track, warning sign A 21 "Cyclists", with supplementary sign "Cyclists crossing", should normally be erected.

B 13

Statutory order on marking of roads, UB 11.2 "Bi-directional cycle track"
The supplementary sign indicates that the road that crosses has a cycle track, along which travel is permitted in both directions.

This sign can be mounted below signs B 11 and B 13.

UB 11.2



Circular on marking or roads, UB 11.2 "Bi-directional cycle track"

UB 11.2 shall be mounted below B 11 and B 13 if road users approaching from the side road can cross the bi-directional cycle track that crosses the side road.

UB 11.2 shall also be mounted if a bi-directional cycle track starts or ends at the relevant side road.

When driving out from a road crossed by a bi-directional cycle track in an urban area, the "give-way" line shall be marked with S 11 "Give-way line" and B 11 "Give way unconditionally" at the right-hand side of the secondary road.

Marking with B 11 also applies if traffic at a four-leg intersection can cross a cycle track on the opposite side of the intersection.

Bi-directional cycle tracks occur more often outside built-up areas than inside built-up areas (see also par. 2.4. on bi-directional cycle tracks). The compulsory requirements for bi-directional cycle tracks apply to both inside and outside built-up areas.

Circular on the establishment of bi-directional cycle track along roads

C. Bi-directional cycle tracks at intersections controlled by traffic lights.

1) Regardless of the traffic intensity, the manner in which they shall behave in the intersection must be clear to all permitted streams of cycle traffic. Thus, the way in which turning is permitted shall be clearly and unambiguously indicated to all streams of cyclists turning into or from the bi-directional cycle track. The directives must only demand behaviour that can be expected of cyclists. If a turning cycle stream is not controlled separately, the sequence of signals issued by any signalling system with more than two phases must be considered "natural." The sequences used must not be so unexpected that cyclists undertake the turn at an unsuitable point in any sequence.

2) When a bi-directional cycle track is located to the right of a motor vehicle lane with right-turning traffic, and the two traffic streams share a common green period, the width of the bi-directional cycle track over a suitable distance before the stopline must not exceed 3 m and that of any dividing strip towards the vehicle lane must not exceed 0.5 m.

3) The two opposing streams of a bi-directional cycle track shall receive the green light at the same time. Moreover, the cyclists shall receive the green light at the same time as a pedestrian area beside the cycle track. However, small deviations resulting from differences in time taken to leave the area can be tolerated.

4) Conflicts between right-turning motorists and cyclists travelling in the opposite direction, and between left-turning motorists and cyclists travelling in the same direction, can be resolved through separate control of the turning vehicles or through separate control of the cyclists. If this is not the case, the motor vehicles' turns must be undertaken from a single vehicle lane, which must not be used by vehicles travelling straight ahead. Moreover, such conflict situations shall be apparent under all conditions. In all situations, there shall be clear markings with traffic signs and lane markings and the cycle track shall at least be illuminated in accordance with the Circular of September 26, 1979, on road illumination, Paragraph 2.1.7, Item 4, and Paragraph 2.2.4.

5) If cyclists from a bi-directional cycle track are controlled by separate sets of lights, there shall be a minimum of two sets of special cyclist lights for each direction. Only normal traffic lights shall be erected when cyclists from a bi-directional cycle track can ride straight ahead at the same time as motor vehicles can turn, unless there is a particular reason for cyclist lights governing the relevant direction to operate in a sequence other than that of the main traffic lights. Thus, different types of lantern can be used for each stream of the cycle track.

6) After taking a bi-directional cycle track-crossing controlled by traffic lights into operation, and in the event of any subsequent change in the traffic conditions of such a crossing, special care must be taken to check that traffic flows with a reasonable degree of safety. Especially in the case of major intersections, it may be found necessary to erect clearer markings than were originally considered necessary or to use traffic lights to control potential conflicts, if such conflicts involve greater risks than were originally expected.

Stoplines

In conjunction with traffic-light control, stoplines are normally located 0.1 to 0.5 m from the pedestrian zebra crossing, cf Road Standards for marking of lanes. However, out of consideration for the safety of pedestrians against vehicles that start too early, and for cyclists against right-turning cars, consideration should be given to whether the stopline for motor vehicles should be located between 4 and 5 m from the pedestrian zebra crossing. In connection with this, stoplines on cycle tracks are recommended to be located close to the intersection.

Safety effects on recessed stoplines for car traffic in signalized urban intersections have recently been documented in the ongoing Danish research project on "Safety of cyclists in urban areas". (10)

Traffic Islands

The break in the cycle crossing is recommended to be of the same width as the cycle track and without any raised kerbstone.

Geometry of roundabouts

Out of consideration for the safety and security of light road users, only a single access lane and a single exit lane should be constructed on each of the roads.

Where cycle tracks are established, their minimum width is recommended to be 1.7 m, including the edge line or kerbstone.

Where it is considered necessary to reduce the speed of cars, humps can be located in the approach, about 5 to 10 m from the circulation area, or else the roundabout's cycle track and pavement can pass the road fork as an exit construction (cf. Fig, 2.3.5). Also where there is only limited traffic, cycle tracks and pavements can pass a road fork as an exit construction.

Pedestrian crossings and cycle tracks or lanes should normally be located directly adjacent to the circulation area. The give-way line on the access road should be located before the pedestrian crossings.

Recessed pedestrian crossings and/or cycle track crossings can be justified by the unacceptable risk of queuing back into the circulation area or by the special circumstances prevailing when a bi-directional track passes a roundabout.

A recessment of pedestrian/cyclist crossings should be at least 10 to 15 m and should be accompanied by an unconditional obligation to give way to right-turning traffic, possibly supplemented with a cycle gate.

If the degree of staggering is too great there may, in certain cases, be a risk that cyclists use the vehicle lane instead of the cycle path around the roundabout.

There is insufficient knowledge on accidents at roundabouts to choose between cycle lanes, cycle tracks or neither in the circulation area (**14**).

The construction of cycle tracks demarcated by kerbstones can be justified by:

- greater security (= feeling of safety) for the cyclists
- less risk of crowding from vehicle traffic
- less inclination to cut corners on the part of cyclists
- natural continuation of the cycle track along one or more of the road forks
- narrower construction and appearance, which results in reduced vehicle speed.

Where a cycle track or lane is constructed at a roundabout, it should be continued some distance along any road forks that otherwise lack cycle tracks or lanes (streamed cycle track). This is especially important on the approach.

Where there is a cycle track or lane alongside the circulation area, it should be marked as a cycle area where it passes the road forks. The cycle-area marking shall either be coloured blue or comprise two concentric broken lines (0.5-0.5). Moreover, it shall be marked with cycle

symbols that are clearly visible to motorists entering and leaving the roundabout.

The Danish road standards on roundabouts are in general based upon special attention to safety of cyclists. The conflicts between circulating cyclists and entering and exiting cardrivers cause high risk situations to cyclists in urban roundabouts (**4**).

*The speed reducing design of roundabouts leave time enough for the car drivers to observe cyclists and give right of way for circulating two-wheelers with the purpose to reduce risk and increase the feeling of security (**4, 14, 15**).*

*The ongoing research project "Safety of cyclists in urban areas" also include analysis on road users behaviour in roundabouts related to different design solutions (**10**).*

Narrowing
The traffic lane can be narrowed, where it is desired to construct crossings so that they help to reduce the speed of vehicle traffic.

On roads of speed class "Low" and "Very low", which have only low traffic volumes, the carriageway can be narrowed in the immediate vicinity of the intersection to a single lane shared by the traffic from both directions. The lane width should be at least 3.5 m, out of consideration to cyclists, but in other respects should be suited to the turning area required by the design vehicle.

Raised areas and humps
Where it is desired to construct intersections so that they have a speed-reducing effect on vehicle traffic, on roads with a reference speed of 50 km/h or less, raised areas and ramps can be constructed, or humps can be located close to the access and exit routes. The design of speed reducers is described in detail in Volume 7 in the Road Standards of urban areas. (**1**)

Change of road surface
This can be used as a supplementary speed-reducing measure or for the marking of areas that are wholly or partly reserved for particular groups of road user or types of vehicle.

The advantages of establishing such areas should be weighed in each individual case against the accompanying inconvenience, in the form of poor friction, drainage difficulties, maintenance difficulties, noise and inconvenience to light road users.

2.3 5. *Sight at intersections*

Sight area
There must be a clear sight from the stop position of the secondary road at all intersections where there is an unconditional obligation to give way. There should be a clear sight from this point to the motor vehicle lanes on the primary road and to any cycle track on the primary road.

The necessary sight of the cycle track will often fall within the area of sight needed for a sight of the motor vehicle lane. In other cases, an additional triangle may be needed, as shown in Fig. 2.3.6.

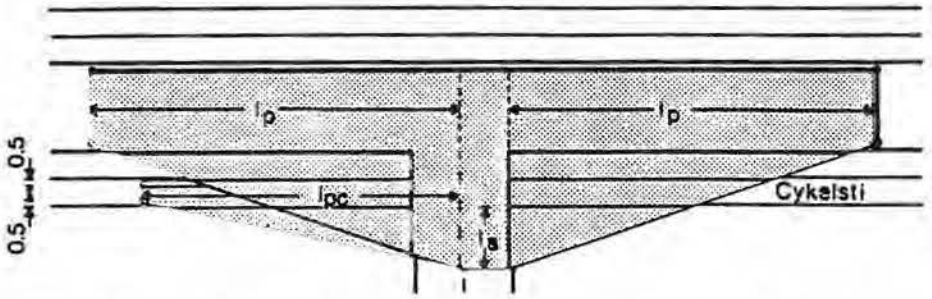


Figure 2.3.6. Sight area, intersection with cyclists on primary road.

Where it is especially difficult to arrange sufficient sight, l_s can be calculated from the carriageway, instead of from the edge of the cycle track, as far as the sight of the carriageway is concerned; see Fig. 2.3.7.

In the case of bi-directional cycle tracks along the primary road, sight should be provided to the right and to the left. Where uni-directional cycle tracks are, in practice, used as bi-directional, it can also be of relevance to provide a sight of both sides.

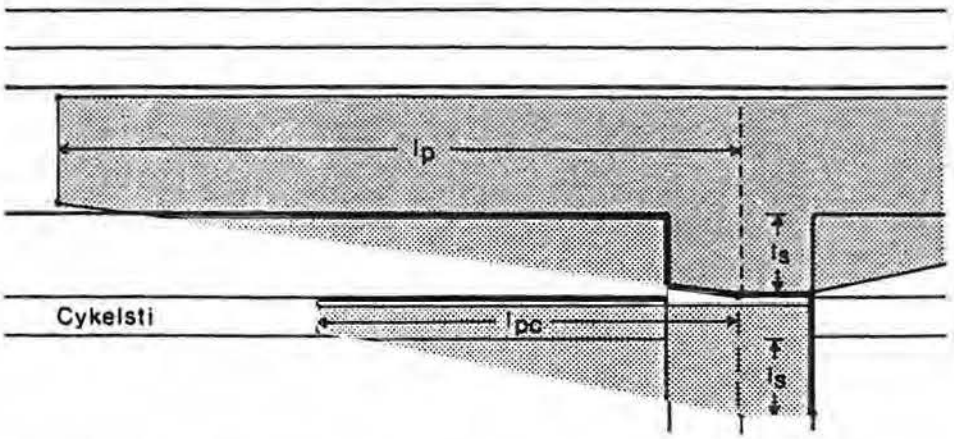


Figure 2.3.7. Sight area, intersection with cycle track on primary road, complex conditions.

In the case of new constructions, and whenever possible elsewhere, the sight lengths l_s and l_p should satisfy the following requirements: l_s: 2.5 m. This distance corresponds to the normal eye position of the users of the secondary road.
The distance l_p along the primary road should be of at least the value shown in Fig.2.3.8.

Reference speed (km/h)	80	70	60	50	40	30
Sight distance l_p (m)	175	145	120	95	75	55

Figure 2.3.8. Sight distances along primary road.

The distance l_{pc} along the primary road's cycle track should be at least:
- cycle track with moped traffic: 45 m
- cycle track with cyclists only: 33 m

Conditions
The above sight distances promote safety for both motor vehicles and cyclists when crossing or turning under the following conditions:
- speed, motor vehicles on primary road: reference speed
- speed, mopeds: 30 km/h
- speed, cyclists: 25 km/h
- orientation time for road users from secondary road: 2.5 s
- braking reaction time: 2.0 s
- deceleration, vehicles: 3.5 m/s^2
- stopping distance, mopeds: 25 m
- stopping distance, cyclists: 16 m

Higher speeds, lower deceleration rates, etc., can also be encountered but, in practice it is assumed, for instance, that higher speed on the part of cyclists will be compensated by greater attentiveness and/or better brakes.

Sight before intersections
In the case of new constructions, there are normally no requirements on sight before intersections, ie of and for secondary road users approaching the crossing.

Height of sight space
With consideration of snow, grass, etc., vehicle lane areas, cycle tracks and pavement areas, traffic islands, dividing islands and shoulders within the sight area are recommend to be at least 0.2 m below the sight space. The same applies to road equipment within the sight area.

Sight for road users turning left
Left-turning road users will need sufficient sight to ensure a safe crossing of the opposing vehicle lane and of any cycle track. Thus, care must be taken that two opposing road users do not obstruct each other's view when turning left simultaneously.

The sight distance along the traffic lane for road users waiting to turn left should, therefore, be as shown in Fig. 2.3.9.

Reference speed (km/h)	80	70	60	50	40	30
Sight distance (m)	135	115	100	85	65	50

Figure 2.3.9. Sight distances along traffic lane with turning to left.

The sight distances towards an opposing cycle track are recommended to be: 70 m.

The above distances ensure that a truck can cross the opposing motor vehicle lane or cycle track, respectively, without forcing road users approaching from the opposite direction to brake.

Sight for road users turning right across cycle track
Right-turning road users should have a sight sufficient to ensure a safe crossing of the cycle track. Because of blind angles and insufficient side mirrors, conflicts between right-turning vehicles (especially vans and trucks) and cyclists travelling straight ahead (especially mopeds) are particularly frequent. To reduce the risk of such conflicts, the vehicles are recommended to be given the possibility to drive immediately adjacent to and parallel with the cycle track, for a distance of 20 to 25 m.

An unobstructed view of 70 m to the rear ensures that a truck can cross the cycle track, without a moped rider needing to brake.

2.4. Bicycle facilities at intersections outside built-up areas

2.4.1. *The role of road safety considerations*

In general, for the existing, standards for facilities outside built-up areas it is not completely clear whether road safety was the sole criterion (as is the case for the standards inside built-up areas) underlying the guidelines. During the next years a new series of volumes concerning Road Standards for rural areas will be developed. The aim is to create two parallel sets of Road Standards for situations inside and outside built-up areas. The Danish Road Standards will continuously be adjusted and further developed depending on new experiences and knowledge from research and practice. Traffic safety will be an essential consideration.

The existing standards state that consideration for road safety should be one of the main conditions for the planning of road intersections, for the choice of type of intersection, and for the detailed design of intersections. Thus, it should be easy for road users to recognise intersections and the prevailing right of way, there should be a clear view of other road users and it should be easy for road users to orient themselves and choose their driving directions. Finally, special consideration should be given to light road users: pedestrians, cyclists and moped riders.

Light road users set special requirements on geometric design. Their behaviour is less predictable than that of car traffic and even small inconveniences, in the form of detours or suchlike, can cause undesirable behaviour.

Moreover, the speed of motor vehicles on highways is considerably greater than that of light road users. The risk to these vulnerable road users of severe personal injury is therefore very high.

A clear sight of cyclists approaching from the rear must therefore be ensured for drivers of vehicles turning right.

2.4.2. *Traffic islands and turning lanes for vehicles*

The construction of left-turn lanes is recommended out of consideration for vehicles, cycles, mopeds and pedestrians.

Primary traffic islands and left-turn lanes
The situation is apparent at intersections with primary traffic islands and

left-turn lanes and cyclists, mopeds and pedestrians have a better chance of being observed. Moreover, protected refuges for light road users can be established in the shelter of the primary traffic island. This counteracts especially pedestrian accidents and accident situations 322, 410, 510 and 650, with cycles/mopeds and vehicles as the two parties.

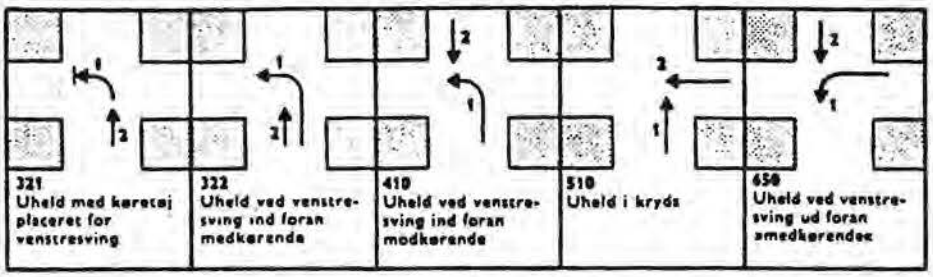


Figure 2.4.1 Accident situations, Nos. 321, 322, 410, 510 and 650.

The three designs of a **primary traffic island**, with kerbstones, without kerbstones and as a painted island, are all to be recommended. The kerbstone-demarcated primary traffic island reduces the potential for avoiding action. On the other hand, painted islands do not offer the same "protection" for cycles and mopeds.

Triangular traffic islands
When constructing triangular traffic islands with separated right-turn lanes on the primary road, there is a risk that motor vehicles are tempted to drive at higher speeds than are really feasible. The establishment of triangular traffic islands can make conditions difficult for cycles and mopeds travelling straight ahead.

Right-turn lanes
Similarly, the establishment of right-turn lanes will make conditions difficult for cycles, mopeds and pedestrians and cannot, for that matter, be shown to be of any safety-promoting value.

2.4.3. *Cycle facilities*

When designing junctions, special consideration should be given to the safety of cyclists and moped riders.

The best approaches can, however, be very costly, for which reason the expected total accident figure must also be taken into consideration when choosing a design.

Crossing conflicts and, therefore, risks of accident, occur where streams of vehicles cross streams of cycles and mopeds. The higher the traffic volume, the more frequent and serious the conflicts.

Criteria for establishment of cycle facilities
Where cycle tracks run along a road that leads into an intersection, the track is recommended to be continued through the intersection. The criteria for establishing cycle tracks along stretches of road are given in "Katalog over vej- og stityper i åbent land" ("Catalogue of road and path types in open landscapes").

It is not possible to give exact criteria for the establishment of cycle tracks at road intersections, where tracks do not run along the stretches of road involved. However, the following verbal criteria can be used as a rule of thumb.

Where there are especially frequent or serious conflicts, cycle and moped traffic should be conducted along cycle facilities in the vicinity of the junction and roads and paths should intersect on two levels.

Where there are fewer and less serious conflicts, cycle and moped traffic should similarly be conducted along cycle facilities in the vicinity of the junction but roads and tracks or lanes can intersect on a single level. Where such cycle tracks are applied (called streamed cycle tracks elsewhere in this report), they should be continued throughout the channelisation stretch, with junctions at the points at which the track begins and ends. However, cycle tracks can possibly be omitted along the secondary road.

There is no need to establish cycle tracks or lanes where the occurrence of conflicts is insignificant.

The following can be said on the design of the various types of crossings.

Intersection on two levels
Where roads and paths intersect on two levels, care must be taken to ensure that cyclists and moped riders are not tempted to use the roads at grade. The path should follow a line that is as direct as possible and shortcuts at grade should be made difficult or, if possible, prevented.

Intersection on a single level - general
Detours should also be limited to the minimum at intersections on a single level and any possible shortcuts should be made difficult or physically prevented without, however, diminishing sight.

Intersections between cycle tracks and secondary roads can be marked as shown in Fig. 2.4.2. The cycle track should possibly be conducted over a secondary traffic island that is at least 3 m wide (including width of kerbstones), so that it is possible to cross the secondary road in two stages.

The intersection between the cycle track and primary road should be as close to the secondary road as possible, but without significantly extending the length of the crossing due to rounding of the junction corners.

Cyclists and moped riders should be able to cross broad primary roads in two stages, with a refuge at a primary traffic island which should,

therefore, be at least 3 m wide, including the breadth of the kerbstones at this point.

Traffic islands demarcated by kerbstones offer the best protection to cyclists and moped riders.

The establishment of cycle tracks along the secondary road, and their alignment is of decisive significance for whether or not cyclists choose to cross the primary road via the refuge at the primary traffic island. Cycle tracks along the primary road can either be routed directly through the intersection or as bent-out tracks.

Cycle tracks routed directly through intersection
Figs. 2.4.2 and 2.4.3 show cycle tracks that are routed directly through an intersection. This method has the following advantage over bent-out cycle tracks:

(1) Right-turning vans and trucks are given a reasonable chance of seeing in their right-hand mirrors cyclists or moped riders who are travelling straight ahead. In this respect, the approach shown in Fig. 2.4.3 is slightly better than that of Fig. 2.4.2.

(2) Cyclists and moped riders travelling straight ahead maintain their direction of travel through the entire intersection and, therefore, do not give right-turning vehicle drivers false reason to believe that they will turn right.

(3) Cyclists and moped riders should not need to make detours (or only insignificant ones). And,

(4) only a small area is required.

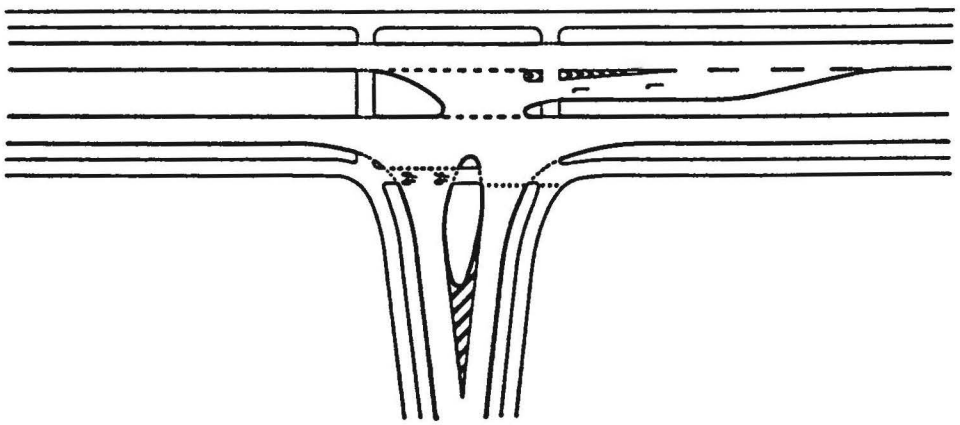


Figure 2.4.2 Intersection on single level, cycle tracks direct through intersection.

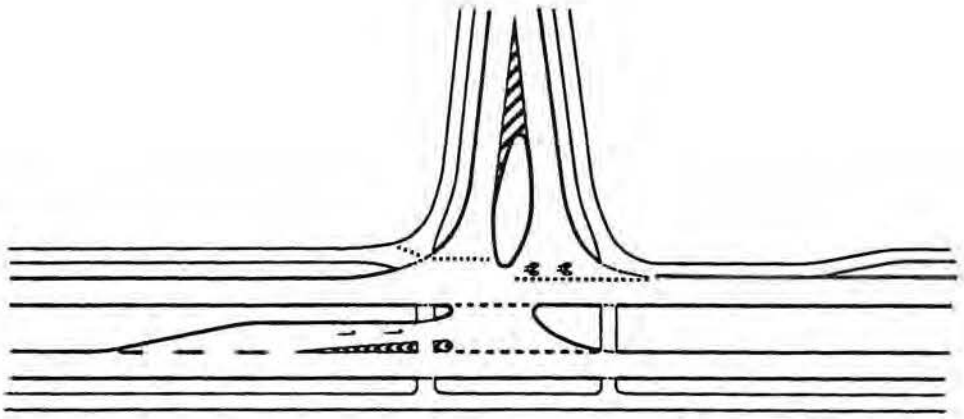


Figure 2.4.3 Intersection on single level, cycle tracks pass directly through intersection, immediately adjacent to motor vehicle lane.

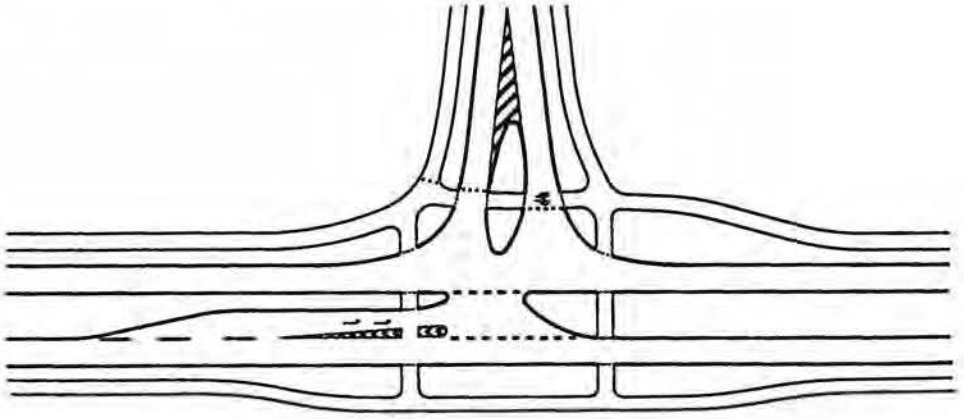


Figure 2.4.4 Intersection on a single level, bent-out cycle tracks

Bent-out cycle tracks

Fig. 2.4.4 shows a T-junction with bent-out cycle tracks. At the intersection with the secondary road, the cycle tracks are bent-out by between 5 and 7 m from the edge of the carriageway of the primary road. This method has the following advantages over cycle tracks that pass directly through the intersection:

- cyclists and moped riders are motivated to reduce their speed
- vehicles turning right are reminded of the obligation to give way to cyclists and moped riders travelling straight ahead
- vehicles waiting to turn right do not obstruct the way for users of the primary road who are travelling straight ahead.

Fig. 2.4.4 also shows a bent-out cycle track at the side of the primary road opposite to the secondary road. This simplifies recognition of left-turning cyclists for cars that are travelling straight ahead and vice versa.

Bi-directional cycle tracks

When crossing a bi-directional cycle track on driving out from a road outside built-up areas, the right-hand side of the secondary road should be marked with S 11, "Give-way line", and B 11 "Give way unconditionally".

Marking with B 11 also applies where it is possible to cross a cycle track on the opposite side of a four-leg intersection.

The compulsory requirements on bi-directional cycle tracks are described in paragraph 2.3 for situations inside as well as outside built-up areas together.

Circular on the establishment of bi-directional cycle track along roads

As the number of cycle routes and side roads is significantly lower outside urban areas, and as the side roads, etc., often carry less traffic than in the towns, there will often be potential for establishing bi-directional cycle tracks along arterial roads outside urban areas.

A. Bi-directional cycle tracks outside urban areas.

1) There should not be heavily-trafficked side roads along the stretch. Where a bi-directional track crosses a heavily-trafficked road outside an intersection, the intersection should be constructed at another level, controlled by traffic lights or interrupted by staggered cycle gates.

3) The establishment of right-turn lanes before side roads has safety value for path users. When right-turn lanes are constructed, the dividing strip towards the vehicle lane should be narrowed down to 0.5 m or be replaced by a kerbstone boundary.

The dividing strip shall be correspondingly narrowed at traffic-light controlled intersections, cf Item c 2 (see par. 2.3).

4) The dividing strips should have a maximum breadth of 4 m. The sight of the intersection shall be sufficient to ensure that vehicle drivers who shall give way to cyclists when crossing the track can, in fact, do so.

6) Bi-directional cycle tracks should, to the greatest extent possible, be terminated at road junctions where road users can be expected to be prepared for crossing road users. At the ends of tracks, cycle gates, fences, railings or other measures should be established that can induce cyclists riding on the left-hand side of the road to reduce their speed. Cycle tracks must not end on stretches where sight is restricted.

Any cycle gates, etc., at the ends of cycle tracks shall be illuminated.

7) Where a bi-directional track running alongside a primary road crosses a small side road and the track is used mainly by cyclists, the track can pass over an exit construction across the side-road junction. Such exit constructions must not be used at major road junctions or at intersections controlled by traffic lights.

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1. Premises for the Geometrical Design
2. Alignment Elements
3. Cross Sections
4. Intersections
5. Path/Road Crossings
6. Path Intersections
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3. The Netherlands

3.1. General rules for bicyclists

The "Reglement Verkeersregels en Verkeerstekens" (RVV & BABW 1990), the Dutch 'Highway Code', has compulsory status and regulates behavioural rules for road users when participating in traffic, including bicyclists. It should be noted that mopeds and electrically assisted cycles ("mofas") have the same status as bicycles in the Netherlands, that is, behavioural rules for bicyclists generally also apply to moped riders. Reconsidering the position of the moped - as a type of motorcycle rather than a type of bicycle - has been under discussion for a number of years. For instance, research has indicated that, inside built-up areas, it is safer for moped riders and other road users that mopeds make use of the carriageway instead of using cycle-tracks (e.g. **9**, **12**).

Two types of *bicycle-tracks* are distinguished in the Netherlands: cycle-tracks that should be used compulsorily and those that can be used voluntarily. Bicyclists use the compulsory cycle-track if present; they use the carriageway if no such cycle-track is present. Bicyclists can use the non-compulsory cycle-track, if present (**6**: behavioural rules; par.1 art.5 and 6). Cycle-tracks are usually located separate from the carriageway, i.e. they are separated from the carriageway by a verge (whereas for instance in Denmark, cycle-tracks are usually separated from the carriageway just by curbstones). The two different types of cycle-track are indicated by traffic signs as illustrated below (figures a and b, respectively).

(a) Compulsory cycle-track *(b) Non-compulsory cycle-track*

Bicycle-lanes indicated by continuous, uninterrupted lines on the carriage-way may only be used by bicyclists, moped-riders (and by drivers of special vehicles for the disabled); other road users are not allowed to use these cycle-lanes (**6**: behavioural rules; par.1 art. 10). *Recommended lanes* are indicated by interrupted lines on the carriageway. The difference between cycle-lanes and recommended lanes is that the former must be used by bicycles and must not be used by motor vehicles, whereas recommended lanes can be used by both categories of road user. Cycle-lanes are indicated by lines and a bicycle-sign painted on the road (often the cycle-lane itself is painted in red), whereas recommended lanes are merely indicated by an interrupted line painted on the road.

When no specific right-of-way ruling is present at intersections, i.e. at intersections without priority signs or markings, traffic should submit right of way to traffic from the right. *However, cyclists and moped-riders must always submit right of way to motorists at intersections without right-of-way regulation* (**6**: behavioural rules; par.5 art.15). The only exception to this rule is at 'erven', i.e. special residential areas in which all road users have the same status.

When a lighted image of a bicycle is shown on traffic lights, this traffic light holds for bicyclists and moped-riders only (**6**: traffic signs; par.3 art.3). When a sign is present with the text "Free right turn for bicyclists and moped-riders" below or close by a traffic light, these road users do not have to comply with the red and yellow lights when they turn right (**6**: traffic signs; par.3 art.5).

Regulations for implementation of the behavioural rules, e.g. how and where to place road signs, markings on the road etc., are described in the so-called "Besluit administratieve bepalingen inzake het wegverkeer" BABW (**6**).

3.2. Status of standards for bicycle facilities

In the Netherlands *no compulsory standards exist with regard to bicycle facilities at intersections*. Standards do exist for traffic signs, markings, and traffic lights in general, but not for specific bicycle facilities.

3.2.1. *Guidelines for bicycle facilities at intersections*

The ASVV Handbook (**1**) contains numerous guidelines and recommendations for road facilities *inside* built-up areas, including bicycle-facilities at intersections. Throughout the book all facilities mentioned are marked by a number of 'stars' (1 to 5) which indicate their status; the higher the number of stars the more 'mandatory'. Five stars indicate compulsory standards; four stars indicate guidelines which may only be deviated from when grounded motivations are supplied; three stars indicate recommendations because it is usually assumed that such facilities are beneficial, etc. In this report only the facilities with relatively 'high status' as offered by the ASVV Handbook are summarized. However, no compulsory standards for bicycle facilities at intersections are available. So, five stars do not occur; four stars usually refer to road markings (**7**), most facilities have three stars (= recommended). Two and one star facilities are *not* summarized in this chapter.

The so-called RONA guidelines contain guidelines for road facilities at non-motorways *outside* built-up areas. For the paragraphs on these facilities two volumes of the series have been used: the volume on bicycle facilities along road stretches (**3**) and the volume on intersections in general (**4**). Separate guidelines for bicycle facilities at intersections outside built-up areas are still in preparation. The RONA guidelines come close to being compulsory, in the sense that they can only be deviated from when grounded motivations are present (i.e. comparable to the 'four stars' indication in the ASVV Handbook).

A recent publication, called 'Sign up for the bike' (**5**) contains numerous

recommendations for bicycle facilities, some equivalent with either ASVV or RONA guidelines, others are additional recommendations. This book (5; p. 8) states that "the ASVV Handbook contains a great number of useful recommendations for designing cycling-facilities, mainly in the form of examples. [..] Integration with the requirements of other modes of transport is attempted in the handbook, which quickly leads to compromises". All recommendations in this book are based on the 'bicycle' as a starting point, hence the subtitle: A design manual for a cycle-friendly infrastructure. Much attention is paid to, for instance, 'comfort' for bicyclists and 'directness' (i.e. avoiding detours as much as possible). The status of the recommendations in this book is comparable to the 'three stars' (or less) indications as have been used in the ASVV Handbook.

Since the purpose of this report is to summarize existing *standards* for bicycle facilities at intersections, the main sources that have been used for this chapter are the guidelines marked with 'three or four stars' in the ASVV Handbook (1) for situations inside built-up areas (par 3.3.) and the RONA guidelines (3, 4) for situations outside built-up areas (par. 3.4.). Of all available guidelines these come closest to being 'standards'. Sometimes other recommendations are summarized as well, particularly when the main sources do not mention facilities that are often applied in the Netherlands. It is explicitly stated in the text whenever this type of recommendations is mentioned.

3.3. Bicycle facilities at intersections inside built-up areas

3.3.1. *The role of road safety considerations*

The criteria for evaluating road facilities inside built-up areas which are used in practice can be divided into two categories. One category concerns the functioning of the traffic system itself (internal criteria); the other concerns the influence of the traffic system upon other events in society (external criteria).

Internal criteria are:
(1) Smoothness (also called traffic flow), which can, for example, be measured by the mean trip-speed.
2. Traffic safety, which is usually measured by counting the number of traffic accidents and victims of these accidents.
3. Comfort (this criterium is hard to define and quantify).

External criteria are:
4. Accessibility, which can, for example, be measured by means of the transition speed.
5. Physical hindrance, for example noise polution.
6. Psychological effects (mostly subjective measurements).
7. Economic criterium.

The list of criteria makes clear that although traffic safety is an important criterium for the recommendations with regard to road facilities inside built-up areas, it is not the only or most important criterium; one strives for an integrated approach in which all criteria are taken into account (1; p. 251-252).

For bicycle routes and networks, requirements are formulated which can be conflicting, in which case the pros and cons should be weighed up. For instance, bicycle routes should be as direct as possible, as continuous as possible, as comfortable, attractive and safe as possible, and with delays and height differences kept to a minimum (**1**; p. 236).

Similar criteria for bicycle facilities are listed in 'Sign up for the bike': They are called the five essential requirements for cycle-friendliness. These can be summarized as follows: (1) Coherence, i.e. the cycling-infrastructure forms a coherent unit and links with all origins and destinations of cyclists. (2) Directness, i.e. the cycling-infrastructure continually offers the cyclist as direct a route as possible (so detours are kept to a minimum). (3) Attractiveness, i.e. it is designed and fitted in the surroundings in such a way that cycling is attractive. (4) Safety, i.e. it guarantees the road safety of cyclists and other road-users. (5) Comfort, i.e. the cycling-infrastructure enables a quick and comfortable flow of bicycle-traffic (**5**; p. 24). Note that these requirements are based on the 'bicycle point of view', and in that regard differs from the criteria as used in the ASVV Handbook in which for all criteria all types of road users are considered. In both sets of criteria or requirements road safety is (only) one of many others. No indications are given as to their mutual weight.

3.3.2. *Types of cross section at roadstretch leading to intersection*

An intersection has three, four or sometimes even more legs: the road-stretches leading to the intersection. In addition, each of these roadstretch-es can differ from one another with respect to their traffic characteristic. Hence, the total number of possible facilities at intersections is a multiple of the types of cross section that can be distinguished for the various road stretches (see table 3.3.1). Therefore, it is not possible to give a limited set of 'basic solutions' for facilities inside built-up areas (**1**; p. 391).

Starting points for designing bicycle facilities at intersections are the types of cross section of the road stretches leading to the intersections (see table below). These profiles are, in principle, continued across the intersection. In certain cases, for instance when there is lack of space, this principle can be deviated from (**1**; p. 392).

Intersections with signal control, and roundabouts will be discussed in par. 3.3.7. and 3.3.8., respectively.

Physical separation	see par.
- rightsided cycle-track	3.3.3.
- leftsided cycle-track	3.3.4.
Visual separation (cycle-lane or recommended lane)	3.3.5.
Mixing	3.3.6.

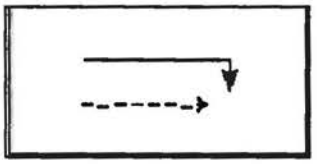
Table 3.3.1. Types of cross section at roadstretches leading to intersection

The possible conflict-types between bicycles and motor vehicles serve as a starting point to choose the appropriate facilities. In order to indicate conflict-types, bicycles are indicated by dashed lines, and other vehicles by uninterrupted lines.

3.3.3. *Right-sided one- or two-way cycle-track*

Bicyclists turning right at this type of profile seldom have problems with motor vehicles. The most encountered conflicts are those between bicycles turning left or riding straight ahead and motor vehicles (**1**, p. 394).

Possible conflict:



Recommended facility:
Bending-in of cycle-track (in case of one-way cycle-tracks only), which increases the visibility of bicycles (**1**, p. 562; see figure 3.3.2. for an illustration).

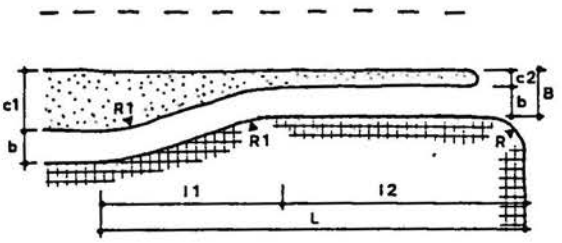
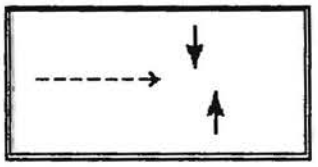


Figure 3.3.2. Illustration of bending-in.

Possible conflict:



Recommended facilities. Refuge in the road to be crossed, which allows bicycles to cross in stages (**1**, p. 610) in combination with a priority regulation by means of road signs at the intersection; in general the priority regulation will be similar to that of the carriage way (p. 756). The crossing should be indicated by painted markings which facilitates recognition of the possibility that bicycles can be encountered at the intersection (**7**). See fig. 3.3.3.

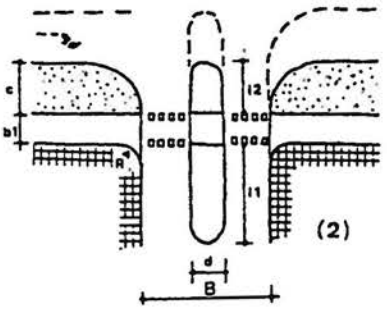
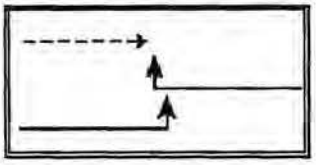


Figure 3 3.3. Illustration of refuge in road to be crossed

3.3.4. *Left-sided two-way cycle-track*

At this type of cycle-track located at the left side of the road, particularly conflicts are possible between bicycles coming from the 'wrong', unexpected direction as seen from the point of view of other road users (1, p. 396).

Possible conflict:



Recommended facility:
Road signs to draw attention to crossing bicyclists (1, p. 935, see fig. 3.3.4.)

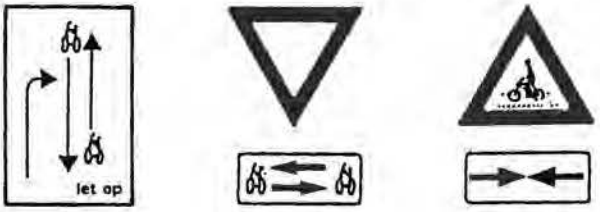
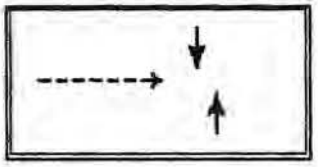


Figure 3.3.4. Illustration of road signs to draw attention to crossing bicyclists.

Possible conflict:



Possible facilities:
Continue the type of pavement and/or its colour (usually red) over the secondary road (p. 830), and regulate the priority at the intersection such that bicycles have right of way at the intersection.
See figure 3.3.5. (Q= rumble area to enable heavy vehicle turns, but discouraging short-cuts by cars.)

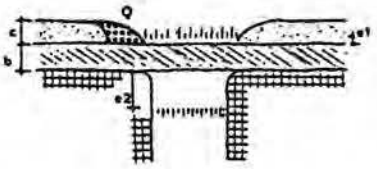
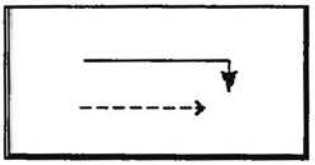


Figure 3.3.5. Illustration of continuing the type of pavement. Note the elevation of the track is continued across the side road.

3.3.5. *Visual separation by means of (recommended) cycle-lanes*

On either one of visually separated bicycle-lane, bicycles seldom have problems when turning right. Possible conflicts and recommended facilities are summarized below.

Possible conflict:



Recommended facility:
Weaving (1, p. 616; see fig. 3.3.6.) can prevent this type of conflict. It shoud be noted that weaving is often considered uncomfortable or unsafe by bicyclists (but there is not much evidence for this).

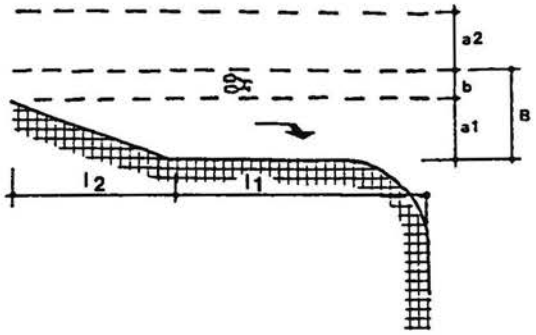
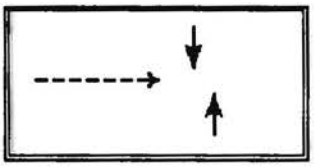
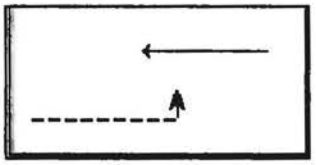


Figure 3.3.6. Weaving right-turning traffic with bicycles.

Possible conflict:



or:

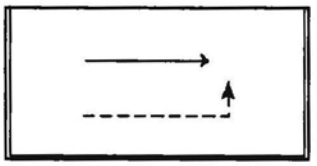


Recommended facility:
For both types of conflict refuges can be applied to enable bicyclists to cross the intersection in stages (see also figure 3.3.3).

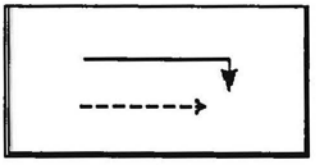
3.3.6. *Mixing*

When bicycles are mixed with the other road users, i.e. no bicycle-lanes or tracks are present, the following conflicts and recommended facilities at intersections can be summarized. Usually bicycles turning right do not have problems with other road users.

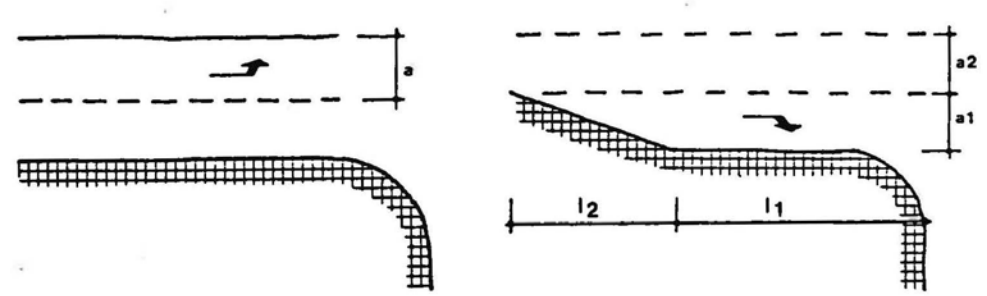
Possible conflict:



or:



Recommended facility:
Weaving (p. 614, 616). A separate lane on the carriage way for left turning or for right turning traffic, respectively, should be applied (see figure 3.3.7. a and b). It should be noted that left-turning bicycles can have conflicts with motor vehicles behind them (a).



(a) *(b)*

Figure 3.3.7. (a) and (b). Illustrations of weaving.

Possible conflicts between bicycles crossing the intersection straight on and crossing motor vehicles from the intersecting road can be diminished by placing refuges in that road to enable bicyclists to cross the intersection in stages (see also fig. 3.3.3.).

3.3.7. *Traffic lights*

General
In principle, traffic light installations can be applied at intersections of all various types of profiles as discussed in the previous paragraphs. In order to resolve problems at an intersection with regard to traffic flow, traffic safety or otherwise, a traffic light installation should only be considered when other solutions are not feasible. In many cases, a limited reconstruction of the intersection is a better solution (**1**; p. 255).

Several criteria have been developed for the application (or removal) of traffic lights. If, and to what extent, a traffic flow problem is present can be determined by means of the *volume-criterium*; various methods of

calculation are available. Another criterium that can be used is based on the so-called acceptable *'lost time'*, i.e. the extra time that is needed to cross an intersection because of the presence of other road users compared to a situation without other road users.

The *safety-criterium* is usually based on analyses of accidents and near-accidents (traffic conflicts).

These criteria are of help to form a balanced decision in a manner that is as objective as possible. However, local circumstances will always play a role as well. The application of traffic lights is no guarantee that no accidents will happen anymore (**1**; p.256). For instance, research has shown that approximately 48 % of the accidents between bicycles and motor vehicles at (a sample of) 'large' intersections still happen at those regulated by traffic lights (**11**).

Concerning bicycle facilities
In the interest of the safety and comfort of bicyclists it is recommended that they have the opportunity to cross the legs of intersections with one or more traffic islands in one continuous movement, as much as possible. This also applies to cyclists turning left when they have to cross two legs successively. For cyclists turning right it is recommended that facilities are present that allow them to turn right without having to stop for a red light (**1**; p.725).

The 'checklist for bicycle facilities at intersections' in the ASVV Handbook summarizes the following aspects with regard to traffic lights (**1**; p. 371):

- if possible, avoid the need to apply traffic lights by adjusting the intersection in another way;
- decrease the mean and the maximum waiting time for cyclists, for example, by offering 'green' more often per cycle;
- design detectors at a certain distance before the traffic light to increase the probability for the bicyclists not having to stop at the intersection;
- give bicyclists the possibility of turning right by red, or a free right-turn, if possible;
- pay special attention to bicyclists turning left;
- if possible, create green phases for bicyclists in such a way that they don't have to wait more than once to cross large intersections;
- avoid (whilst taking their safety into account) early cut-offs of the green phase for bicyclists;
- check how the intersection functions when the traffic lights are switched off.

To avoid possible conflicts between bicycles and motor vehicles it is recommended that traffic light installations are regulated conflict-free, that waiting time is short, that there is a general bicycle phase (i.e. while bicyclists are offered green, all other traffic is given a red phase), and that the stage order is friendly for the cyclists. A general bicycle phase is seldom applied because of the uneconomical usage of time.

With regard to possible conflicts between bicycles going straight ahead

and motor vehicles turning right, an early start for bicycles is recommended.

At intersections with mixed traffic or visual separation, weaving, expanded bicycle streaming lanes (EBSL; see below), or refuges are recommended (see p. 886-888).

Turning right
A separate facility is preferred, in which cyclists can turn right completely regardless of the traffic-light regulation; this solution is indicated with *turning right by red* (**1**, p. 404, 558; **5**, p. 180). For illustrations, see figure 3.3.8.

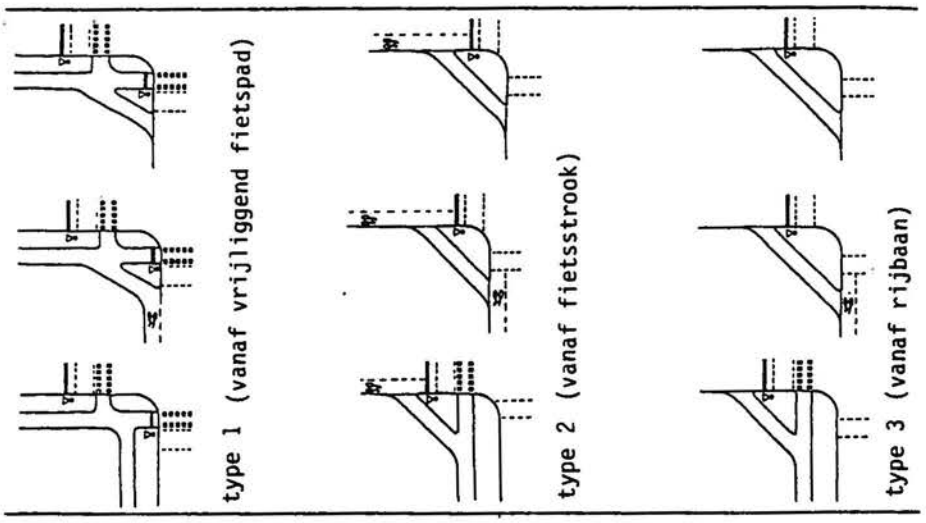


Figure 3.3.8. Turning right by red for various road cross sections. (a) From cycle-track; (b) from cycle-lane; (c) from carriage way.

If separate facilities for cyclists passing by the controlled area are not attainable, applying a free right-turn for cyclists - while they are faced with a red light - can be considered. This facility is often indicated by *turn right on red.*

The difference between turn right *by* red and turn right *on* red implies that by turning right by red bicycle-traffic in principle flows outside the traffic-light regulation, whereas cyclists turning right on red are allowed to turn right while faced with a red light. In principle cyclists turning right on red should give priority to all other traffic, pedestrians included. The number of conflicts which the right-turning cyclist is simultaneously confronted with, depends on the traffic light regulation at the intersection. If these conflicts are permissible, then free turning right is possible at each red phase for cyclists (and mopeds). This is then indicated by a fixed road-sign with the text "free right-turn for cyclists and moped riders" (**1**, p. 404, 559; **5**, p. 181). This text is sometimes displayed during some of the red phases only; then the sign is an illuminated one that is switched on during these phases only.

Turning left
When bicycles turning left can get into conflict with motor vehicles going straight ahead, a so-called expanded bicycle streaming lane (EBSL) can be applied (**1**, p. 886). The facility is also used at busy intersections with great numbers of bicyclists in order to create more space for them to wait for the traffic light. The EBSL is only applied at intersections inside built up areas with mixed traffic equipped with traffic-lights.

The EBSL consists of a separate streaming facility for cyclists and moped-riders in front of the streaming spaces for motorized traffic, and of an accompanying approach cycle-lane or recommended lane. The facility makes it possible for cyclists and moped-riders to stream in front of waiting motorized traffic and to cross the intersection area first on a green light (see also **5**, p. 183). For an illustration, see figure 3.3.9 below.

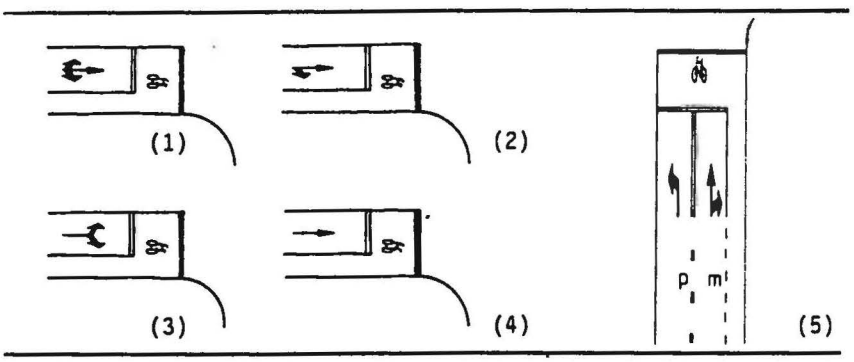


Figure 3.3.9. Illustrations of expanded bicycle streaming lanes (EBSL).

3.3.8. *Roundabouts*

In principle, roundabouts can be applied at all types of road profile (see previous paragraphs). As the preference for the application of roundabouts is only recently developing in the Netherlands, the ASVV Handbook does not yet contain specific recommendations for cycle-facilities at round-abouts.
A recent publication entirely devoted to the topic of roundabouts (**8**) summarizes the following recommendations. On the basis of accident analyses (**10**) it is recommended that a separate cycle-track is preferable for application on roundabouts with a volume of approximately 8,000 motor vehicles per 24 hour period and a significant volume of bicycle traffic. With lower volumes of motorized traffic no preference can be given to particular cycling solutions on grounds of road safety consider-ations, e.g., no cycle facilities (mixing), cycle-lanes, and whether or not bicyclists should have right of way. At present, discussions are going on about priority rulings at roundabouts: research has shown that situations in which bicycles have to give right of way to motor vehicles are safe; for the reverse situation (in which bicycles have priority over motor vehicles), however, no conclusive findings are available yet (**10**). In general, a significant reduction in accidents (including those involving bicycles) has been found when 'common' intersections were changed into roundabouts (**10**).

Although accident statistics do not indicate that other solutions for bicyclists are unsafe, it is considered not advisable to construct roundabouts with a cycle-lane. Due to the application of a cycle-lane the road surface of the roundabout is widened to such an extent that the speed of motorized traffic increases (8).

See figure 3.3.10 for various examples of bicycle facilities at roundabouts.

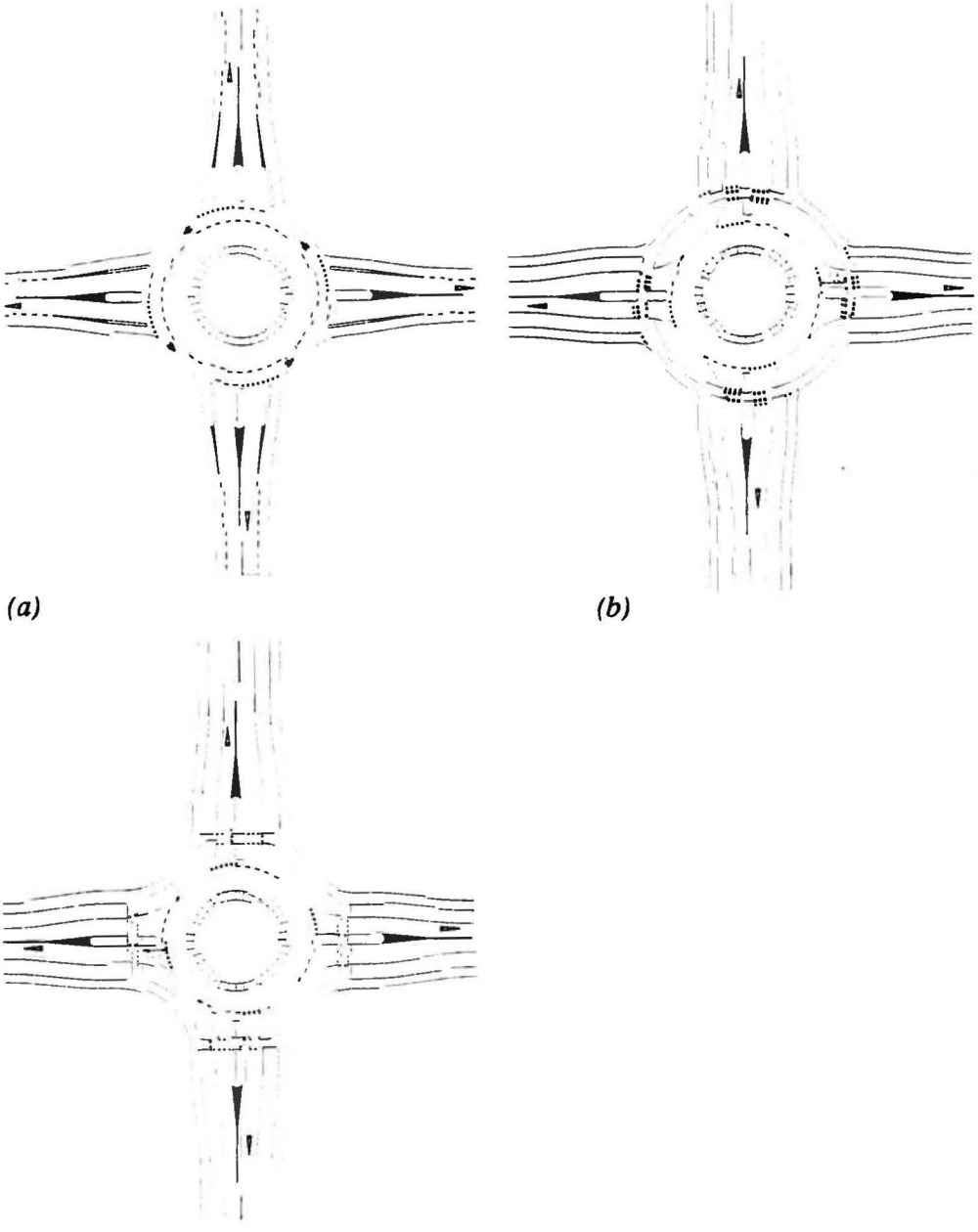


Figure 3.3.10. Examples of roundabouts (a) with cycle-lanes, (b) cycle-tracks and right of way for bicyclists, and (c) cycle-tracks with no right of way for bicyclists.

3.3.9. *Sight at intersections*

Although the ASVV Handbook contains general guidelines with regard to sight distances at intersections, no *specific* recommendations for *bicyclists*

are formulated in this book. Therefore, in this paragraph a summary is given of the recommendations as mentioned in "Sign up for the bike" (**5**).

On designing intersections there are three distances which are considered important by a cyclist:
- sight distance in motion;
- stopping-sight distance;
- approach-sight distance.

Sight distance when in motion
A cyclist should be able to survey the road (cycle-track) ahead and also an intersection over sufficient length so as to make the task of riding safe. In general the minimum sight distance ahead when in motion is considered to be the distance covered by the road user in 8 to 10 seconds. For a determination of sight distance when in motion for cyclists, the design speed for the cycle-track is used. The sight distance when in motion can vary from 45 - 85 m, depending on the design speed for 20 km/h and 30 km/h, respectively (**5**; p. 167).

Stopping-sight distance
The stopping-sight distance is that distance which is needed to react and stop safely. In other words, the distance covered in the perception-reaction time plus the actual braking distance. To be able to anticipate the presence of crossing motorized traffic or bicycle-traffic, the stopping-sight distances for cyclists are greater than the actual braking distance. A perception-reaction time of 2 seconds and a still comfortable braking decelaration of approximately 1.5 m/sec^2 is assumed when determining the minumum stopping-sight distance. According to "Sign up for the bike" the stopping-sight distance is both dependent on the speed of the bicycle and the speed of other vehicles on the road to be crossed. This results in recommended stopping-sight distances varying from approximately 20 - 40 m for cyclists, and from approximately 50 - 150 m distances (for V_{85} = 30 km/u and 70 km/u respectively) along the road to be crossed (= sight triangle). See figure 3.3.11 for an illustration (**5**; p. 167-168).

Approach-sight distance
To be able to cross a carriageway at an intersection safely, cyclists must have sufficient sight of the traffic on a road to be crossed. The amount of approach-sight distance necessary depends on the approach speed of the crossing traffic and the time a cyclist needs to be able to cross safely (crossing length).

In table 3.3.12 (for an illustration see figure 3.3.13) indicative values are given for the approach-sight distances for cyclists, where an acceleration maximum of 0.8 m/sec^2 is assumed, a reaction time of approx. 1 sec and a maximum speed at the bicycle crossing of approx. 10 km/h (=2.8 m/sec) (**5**; p. 169).

crossing length	crossing time approx.	approach speed motorized traffic (V_{85})		
		30 km/h	50 km/h	70 km/h
5 m	4.5 sec	40 m	65 m	90 m
6 m	4.9 sec	40 m	70 m	95 m
7 m	5.3 sec	45 m	75 m	105 m
8 m	5.6 sec	50 m	80 m	110 m

Table 3.3.12. Indicative values for the approach-sight distance for cyclists (taken from 5).

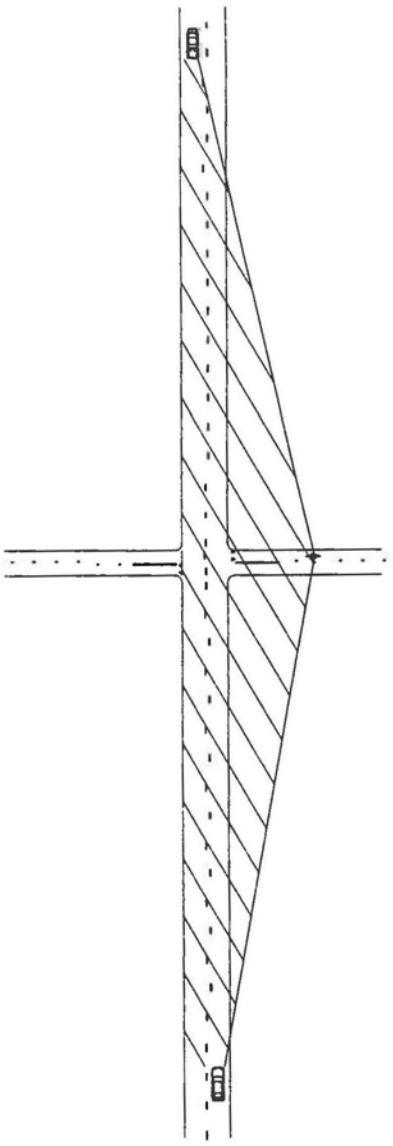


Figure 3.3.11 Stopping-sight distance at an intersection of cycle-route

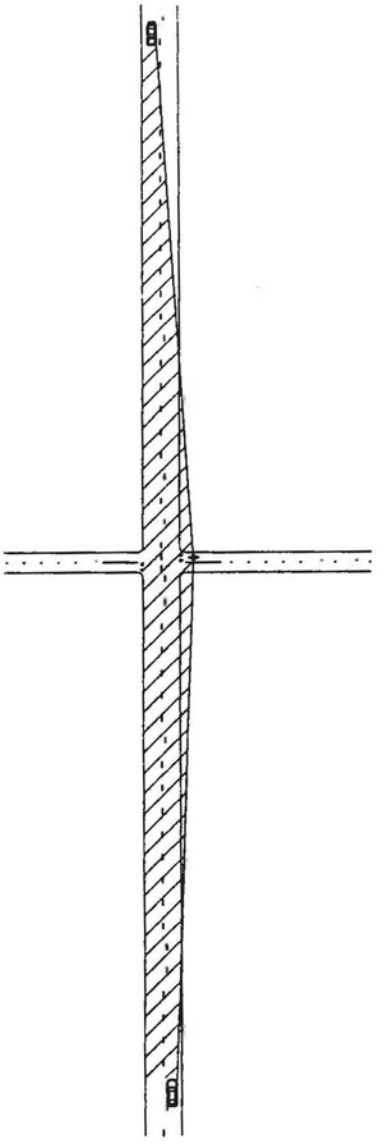


Figure 3.3.13 Approach sight distance for cyclists (Figures taken from 5)

3.4. Bicycle facilities at intersections outside built-up areas

3.4.1. *The role of road safety considerations*

Distinct guidelines for bicycle facilities at intersections outside built-up areas are still in preparation. Therefore, as stated in par. 3.2.1. the general RONA guidelines for intersections outside built-up areas have been used for this chapter. These guidelines state that when designing or reconstructing intersections attention should be given, for several reasons, to the safe passage of all categories of slow traffic such as bicycles, pedestrians, and mopeds (**4**; p. 119):

(1) This group of road users can differ considerably from drivers of motor vehicles with regard to driving experience and education, demographic characteristics and the physical properties of the vehicle. For instance, this group of road users is not protected by the external body of a vehicle, and is therefore much more vulnerable in the event of an accident situation. The potential instability of bicycles also needs to be taken into account in such situations especially due to the speed differential between them and other types of vehicles.

(2) Bicycle facilities at intersections cannot be viewed independently from other, already existing, bicycle facilities along the road carriage-way because they influence one another. *The guidelines for bicycle facilities along road carriageways outside built-up areas (**3**) explicitly state that road safety considerations have been the sole criterium for the guidelines.*

(3) And, more generally, bicycle facilities cannot be viewed independently from the categories to which the crossing roads belong (see Janssen, 1994 for a description of road categories in the Netherlands), since their function, shape and use have consequences for bicycle facilities as well.

Furthermore, the RONA guidelines for intersections outside built-up areas (**4**, p. 119) specify the following general considerations for bicycle facilities:
(a) Bicycle facilities should be designed in such a way that the use of these facilities is attractive for bicyclists. Bicyclists do not accept illogical or unnecessary travel diversions or detours and normally choose the most direct route. Unattractive facilities cause misuse and possibly also result in unsafe riding behaviour.

(b) Bicycle facilities should be clearly marked and must not be mistaken by drivers of motor vehicles as a carriage way or an additional traffic lane.

(c) The design-requirements for bicycle facilities at intersections should, in principle, be equal to the general design-requirements for other intersections.

In recent recommendations for designing a so-called 'cycle-friendly' infrastructure (**5**) similar considerations are summarized as the '5 main requirements': coherence, directness, attractiveness, safety, and comfort (p. 147); with the main difference from RONA guidelines being that these requirements are focused on the 'bicycle-point-of-view'.

3.4.2. *Types of intersections*

RONA distinguishes four types of intersections relevant to bicycle facilities. They have the following characteristics (4; p. 40-41)

type (1)
- no priority regulation by means of signs
- no traffic islands
- no separate bicycle facilities

type (2)
- priority regulation by means of signs
- traffic islands at the secondary road(s)
- no separate facilities for turning traffic
- cycle-tracks or streamed cycle-tracks can be conducted along main and/or secondary road(s)

type (3)
- a priority regulation by means of signs
- traffic islands at the secondary road(s)
- a separate lane for left-turning traffic on the main road
- lane marking and/or separation
- cycle-tracks (or streamed cycle-tracks when roads are open to all types of road user, design speed ≤ 60 km/h; category VII) must be present along main and secondary road

type (4)
- priority regulation by means of signs
- physically separated lanes for each direction on the main road
- on each carriageway one lane for straight on going traffic and a decelaration lane for left-turning traffic; possibly also a decelaration lane for right-turning traffic
- traffic islands on the secondary road
- cycle-tracks must be present along the main carriage-way; along the secondary roads at least streamed cycle-tracks must be present

3.4.3. *One-way cycle-tracks*

Out of road safety considerations it is, in general, preferable that there are one-way cycle-tracks on both sides of the road. Such cycle-tracks along the carriageway can then be conducted through a teardrop-shaped traffic island in the secondary road, and included in the right of way ruling, i.e. turning traffic from the main road should give right of way to bicycles crossing the secondary road. Also traffic from the secondary road must give priority to bicyclists riding on the cycle-track along the main road. The width of the traffic island should allow a bicycle to 'rest' on it while crossing the secondary road.

The intersection between the cycle-track and the main road should be as close to the secondary road as possible. The relation between the main carriageway and the adjacent or adjoining cycle-track should not be interrupted to ensure that bicyclists and drivers of turning motor vehicles can see each other (4; p. 121). See, for an example, figure 3.4.1. and 3.4.2.

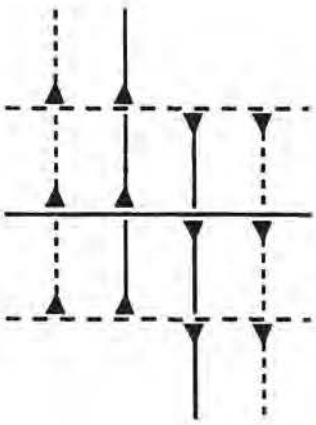


Figure 3.4.1. Schematic presentation of priority regulation of the situation as shown in figure 3.4.2. (below)

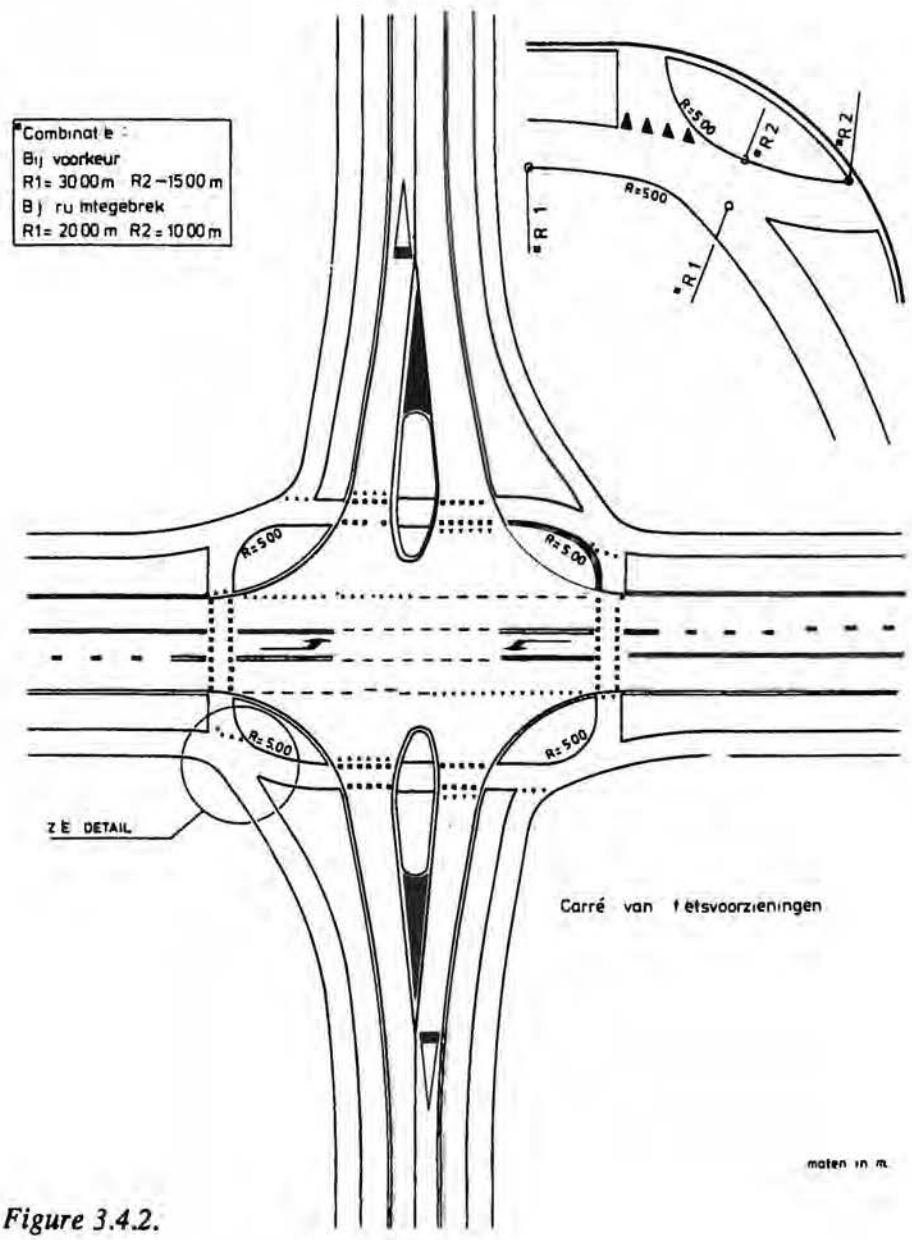


Figure 3.4.2.

3.4.4. *Split-level intersections*

In principle, bicycles and motor vehicles at intersections of motorways with design speeds of 80 or 100 km/h outside-built up areas (categories III and IV) cross at different levels. If it is not possible to apply split-level intersection, other solutions can be employed. However, such bicycle-facilities on roads of these categories can only be applied at intersections that already are controlled by traffic lights. (**4**; p. 126). Also for roads of other categories split-level intersections can be considered. When it is not possible to construct a split-level junction, out of road safety considerations, the cycle-track should be bent-out, and priority-rules should be adapted so that bicyclists should give priority to the motorized traffic (see also par. 3.4.6).

3.4.5. *Two-way cycle-tracks*

If a one-sided two-way cycle-track is applied special attention must be paid to road safety. When approaching a carriageway with an adjacent or adjoining cycle-track, in general the orientation of cardrivers on the secondary road is directed to the left. The bicycle approaching from the right will then come from an unexpected direction. Also turning traffic from the main carriageway can be confronted with cycle-traffic from an unexpected direction. Because of the relatively high speeds of moped-riders it should be taken into account that this group of road users will not be seen at all - or not in time - which can cause serious consequences (**4**; p. 122).

3.4.6. *Bent-out cycle-tracks*

For road safety reasons, two-way cycle-tracks should be bent-out at intersections (preferably until *behind* the raised part of the traffic island in the secondary road), and priority-rules should be reversed so that bicyclists should give priority to turning motorized traffic. The distance from the edge of the asphalting of the carriage way to the crossing will then be 15-20 m, depending on the measurements of the island. In doing so, the relation between the carriageway and the cycle-track is interrupted. To ensure clarity of the situation for the bicyclist small curve-radiuses should be applied when bending-out (**4**; p. 122). See figures 3.4.3 and 3.4.4 for an example. In general, bending-in accompanied by a right of way regulation for bicyclists is not recommended by RONA (Wegen, 1984).

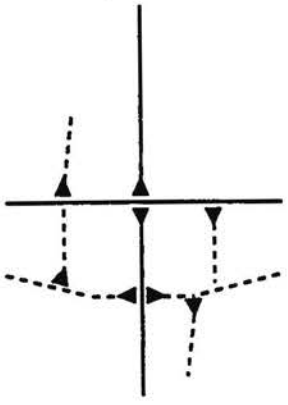


Figure 3.4.3. Schematic presentation of priority regulation of the situation as shown in figure 3.4.4. (next page)

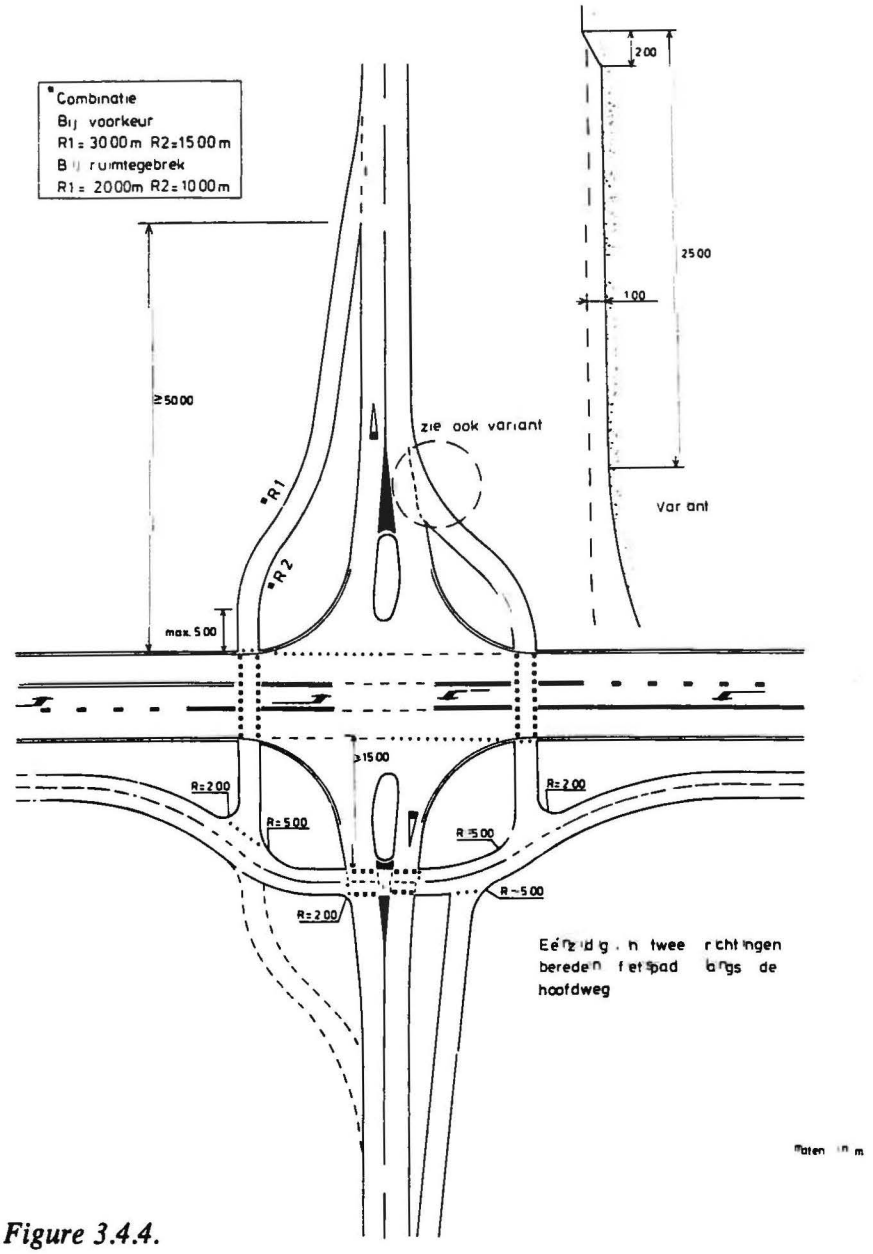


Figure 3.4.4.

3.4.7. *Streamed cycle-tracks*

When streamed cycle-tracks are not applied, the bicyclist will remain in the line of sight of cardrivers which can be considered an advantage. On the other hand, proper application of streamed cycle-tracks has the advantage that at the intersection area itself bicyclists do not cross diagonally. For an illustration of a streamed cycle-track see upper part of figure 3.4.4.

Along secondary roads of category VII (design speed ≤ 60 km/h) streamed cycle-tracks can or must be applied at the the crossing-area, depending on the type of intersection (see par. 3.4.2). The streamed cycle-tracks are an essential part of the secondary road, because cyclists wanting to cross the main carriageway should have right of way over turning traffic from the secondary road. For this reason the relation between the cycle crossing and the carriageway of the secondary road should not be interrupted (4; p. 122).

At T-intersections with one-sided two-way cycle tracks along the carriage-way, two different situations can occur.

(1) The cycle-track crosses the side road.
Along the secondary road streamed cycle-tracks can be applied at intersections of types 2, 3 and 4 (no streamed cycle-tracks should be applied at type 1 intersections; see par. 3.4.2), and the cycle-track is bent-out in such a way that the crossing is behind the traffic-island. Out of safety considerations the priority regulation should be 'reversed': crossing cyclists must then give right of way to both traffic coming from the side road as well as to turning traffic from the main road.

(2) The cycle-track does not cross the side road.
At intersections of type 1 no streamed cycle-tracks should be applied along the side road; at intersections of type 2 and 3 streamed cycle-tracks along the side road *can*, and at intersections of type 4 *must*, be applied (**4**; p. 123).
For an illustration, see figure 3.4.5.

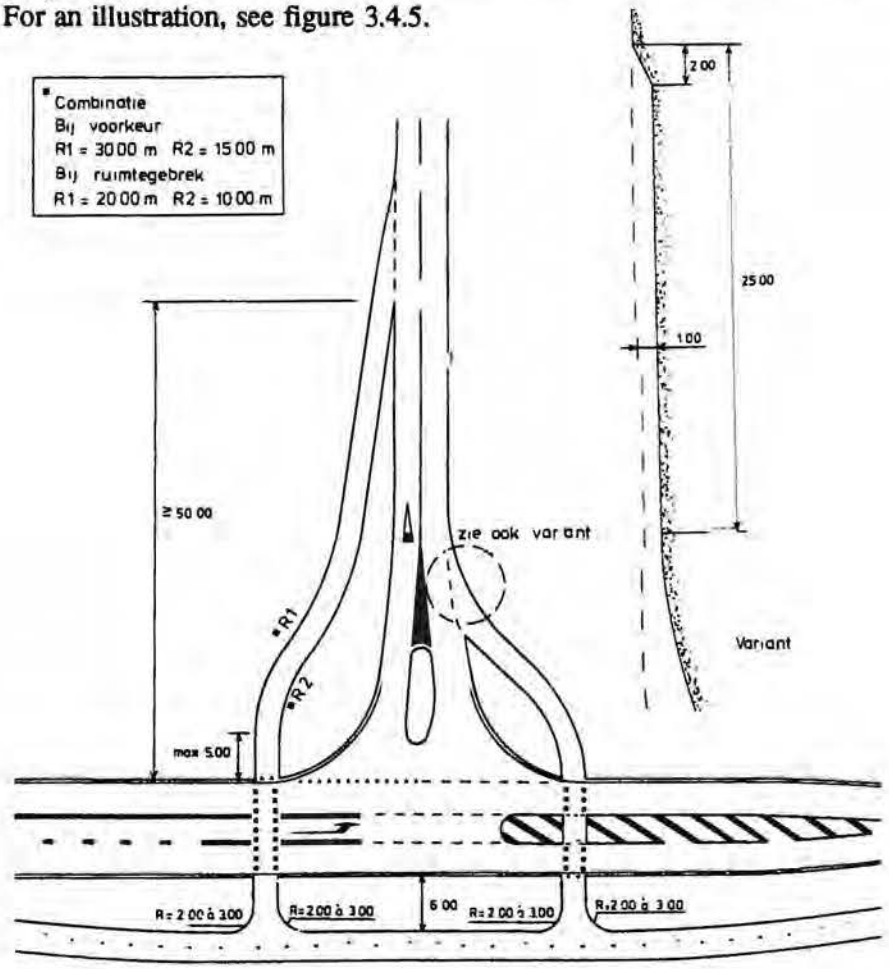


Figure 3.4.5. Illustration of cycle facilities at T-intersection

3.4.8. *Roundabouts*

RONA does not formulate specific guidelines for bicycle-facilities at roundabouts. A recent publication (**8**) states that, in principle, roundabouts with separate cycle-tracks are preferable for situations outside built-up areas. It is recommended that cyclists are not given right of way.

3.5. Bibliography

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4. United Kingdom

4.1. General rules for bicyclists

Cyclists (and users of electrically assisted cycles; mofas) are only entitled to cycle on 'ways' where they have legal authority to ride. They are entitled to ride on carriageways, except motorways or roads from which they have been excluded by a traffic regulation order. Cyclists are also entitled to ride on cycle ways or cycle tracks, which they may or may not share with pedestrians. The cyclist is bound by the rules applying to other road users. Although cyclists can be exempted from restrictions applying to motor vehicles, the cyclist must obey mandatory traffic signs applying to the 'way' he/she is using, including traffic signals (1; p. 208).

4.1.1. *Signs for cycle facilities*

Mandatory cycle lanes
Mandatory cycle lanes should be indicated and bounded by a solid white line broken at each side road junction and for the length of any bus stop incorporated within the lane. The beginning of the cycle lane should be delineated by an inclined broken white line. Cycle symbol markings should be placed at the beginning of, and after every break of the cycle lane, as well as at suitable intervals on long uninterrupted stretches of cycle lane. The termination should be indicated by an 'END' carriageway marking placed immediately beyond the cycle symbol (3; p. 6).
Upright signs are also needed to give advance warning of the cycle lane and to make it clear that it is reserved for pedal cycles only. These are illustrated by diagrams 812.5 and 654.1. To inform traffic in a side road of a lane or lanes in the major road ahead reserved for pedal cycles, or of a cycle track crossing the side road, an informatory sign should be displayed (see diagram 812.6). To inform pedestrians of a lane reserved for pedal cycles, or a cycle track, informatory signs should be erected at all sites used extensively by pedestrians to cross the road (see diagram 810.2).

812.5 Lane ahead reserved for pedal cycles proceeding in the same direction as other traffic (placed in advance of the cycle lane).

654.1 Lane reserved for pedal cycles when proceeding in the same direction as other traffic (placed along the cycle lane).

812.6 To inform traffic in a side road of a cycle lane.

810.2 To inform pedestrians of a cycle lane.

Advisory cycle lanes
Advisory with-flow cycle lanes should be bounded by a broken hazard line, but discontinued at each side road junction. The cycle symbol should be displayed at the commencement of the lane and after each side road junction. Upright signs (see diagram 815) should also be displayed at the start of the lane and then at intervals along the route.

815 Route recommended for cycles

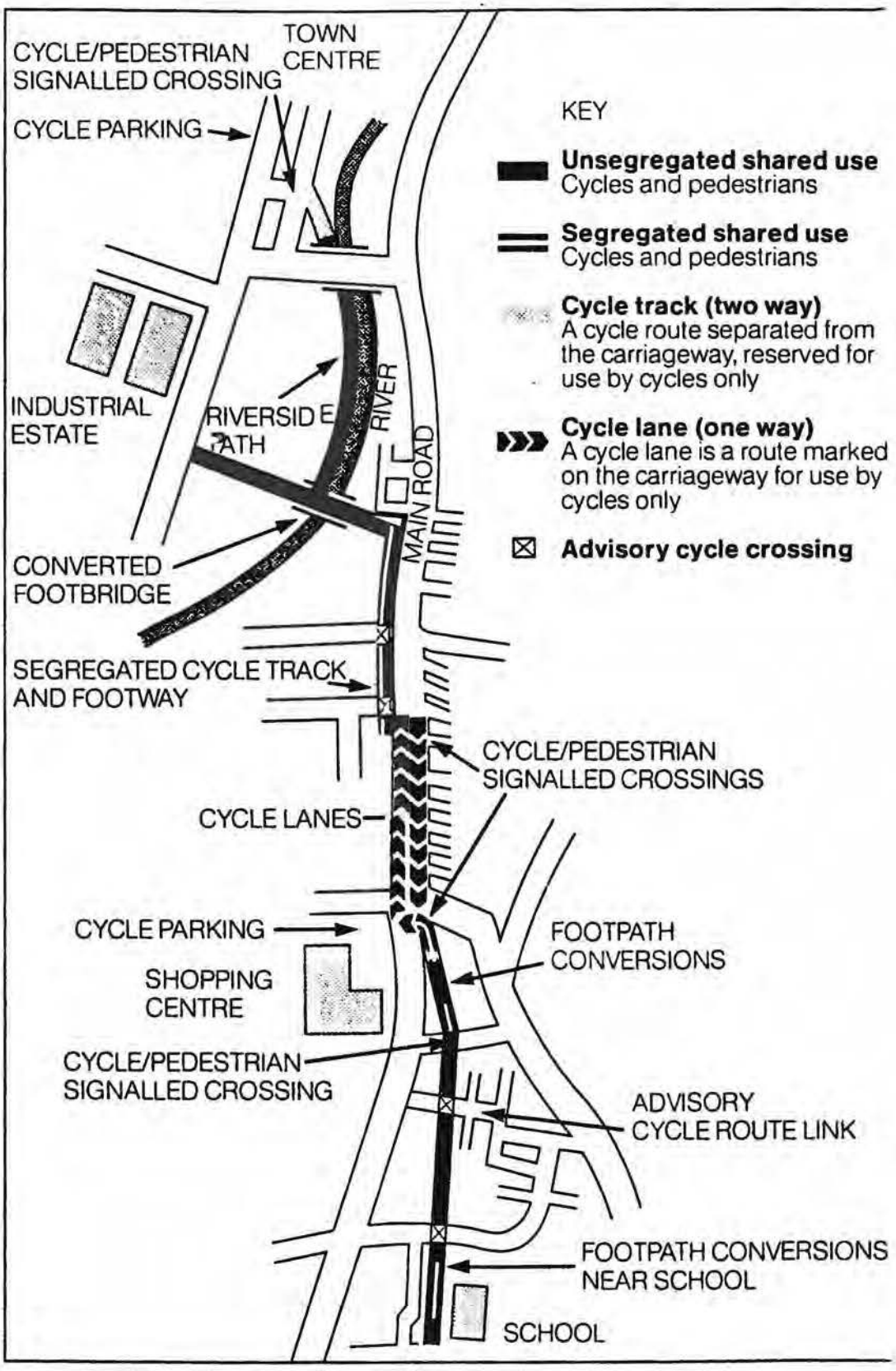
Cycle tracks
Cycle tracks may either be part of a wider highway, or form a highway entirely distinct from the road system. They should be signed by diagram 625 if they are reserved for cycles only.

625 Route shall not be used except by pedal cycles (other vehicles must keep out).

(Diagrams taken from **3** and **4**)

Where cyclists using a cycle track alongside a carriageway need to cross a minor road, traffic on the minor road can be warned of the presence of the cycle track by the use of sign 812.6 (see above) with the permitted variant "CYCLE TRACK". In most cases cycle tracks operate in two directions and the arrow on the sign should be omitted. Pedestrians can be warned of the presence of the cycle track by the use of sign 810.2 (see above) using the permitted variant "CYCLE TRACK". The caption "LOOK BOTH WAYS" should be used if the cycle track is two way.

The figure below shows a schematic diagram demonstrating the various facilities for bicyclists, which are often shared facilities for bicycles and pedestrians (taken from 7):



4.2. General considerations for bicycle facilities

The level of accidents to cyclists causes great concern as cyclists are amongst the most vulnerable groups of road users and are very exposed to injury as a result of collisions with motor vehicles. Their special vulnerability means that the needs of cyclists must always be considered by highway and planning authorities (1; p. 208).

The main objectives in providing facilities for cyclists are, as for other road users, improved safety and increased comfort and convenience. It is important to ensure that the facility is attractive and convenient in order to encourage maximum usage (2; p. 5). Cyclists should not be put at risk or undue inconvenience by other traffic management measures such as long detours, one-way systems or poor siting of signs. Instead, the objectives should be to:

- keep vehicle speeds down where there are significant numbers of cyclists;
- minimise interaction of cycle flows with motor vehicles
- provide continuous and direct cycle routes away from major roads;
- provide safe crossing points at major roads; and;
- recognise the need for cyclists to feel safe as well as being adequately protected (1, p. 209).

4.2.1. *Status of the standards*

Except for signs and behavioural rules, no compulsory standards exist for bicycle facilities at intersections. *All guidelines mentioned in this chapter are recommendations.*

In the guidelines no distinction is made between facilities in- or outside built-up areas.

4.3. Bicycle facilities at intersections

4.3.1. *General criteria*

1. The design of cycle facilities should take into account that the cycle is a vehicle. The layout of junctions on which one or more approaches are restricted to use by cyclists should be similar to a junction of conventional design for motor traffic although there may be some reduction in widths of approach on the cycle route. Where there are cycle tracks at junctions, provision of physical obstacles such as bollards may be required to prevent motor vehicles turning illegally into the cycle facility.

2. Maximum intervisibility between cyclists and drivers is provided by a junction with approaches at, or near, right angles to each other.

3. It may be necessary to provide guard rails at some facilities, such as staggered barriers to channel cyclists' movements. Nevertheless, cyclists may not be inclined to use facilities, however safe, that add greatly to their journey time or repeatedly require them to slow down or dismount.

Thus guard rails that attempt to divert cyclists far from their desire line may cause them to avoid sections of a cycle route. This would be counter-productive in terms of reducing accidents (**2**; p. 5-6).

4. Existing junctions can be modified to make them safer and more attractive for cyclists to use. The emphasis should be on cost-effective solutions which improve the safety and convenience of cyclists (**2**; p. 6). A route for cyclists can be clearly defined through a junction by the use of signs and road markings. At junctions with low traffic flows, priorities can if necessary be changed to favour the cycle route. Where cyclists must give way or stop, an additional lane might be provided for them (**1**; p. 210).

Although safety is an important criterion, usually no safety assessments of specific cycle facilities at intersections based on accident data are available - mainly because there too few of them to measure *accident* savings (Maycock, 1994; personal communication). However, behavioural observations have been made investigating the use of some specific bicycle facilities at intersections. Since many facilities at intersections are shared by pedestrians and cyclists, studies have focused on the aspect of shared use (**8, 9, 10**). The general conclusion of these studies is that sharing of the crossing space by cyclists and pedestrians is satisfactory.

4.3.2. *Major/minor junctions*

At uncontrolled road junctions of the major/minor type the priority of movement is indicated by 'Give Way' markings on the minor road. When the purpose of a cycle route is to divert cyclists from a direct but busy route to a quieter alternative, more cyclists will be attracted if they are not delayed on the new route by having to give way at junctions. Therefore when a cycle route passes along a minor road, consideration may be given to reversing priorities in order to make the cycle route the major road. However, this should only be done in the context of conditions described in the following paragraphs (**2**; p. 15).

If one of the two roads meeting at the junction carries heavy traffic, that road must retain its priority. Even with two lightly trafficked roads, it would normally be unacceptable to remove priority from a road that carried 100 vph more than the other. Apart from the amount of traffic, the strategic coordination of priorities at a series of adjoining junctions may make it unacceptable to change one of them (**2**; p. 15).

Furthermore, priorities at a major/minor junction must not be changed if the drivers who would then be required to give way would have an inadequate view of the cyclists on the cycle route. Visibility requirements for bicycle facilities are equal to the required visibility of traffic on a major road to drivers on a minor road (see paragraph 8.2 of ref **6**).

When the priorities at a junction are changed to accommodate a cycle route, the change must be made obvious. Realigning the kerbs to match the new priorities is one way of doing this, and also has some permanent value in steering the traffic safely (**2**; p. 15).

When the road carrying the cycle route is already the major road, there

should be no question of changing priorities. The visibility requirements apply to all traffic and should already be satisfied, but they need to be checked - and corrected if necessary - before using the road as a cycle route, because cyclists are so especially vulnerable to drivers who fail to see them (2; p. 15).

Where cycle lanes on the carriageway are used for the cycle route (see par. 4.3.1.), the advice of the previous paragraphs continues to apply where they pass through major/minor junctions. The most common case is illustrated in figure 4.3.1.

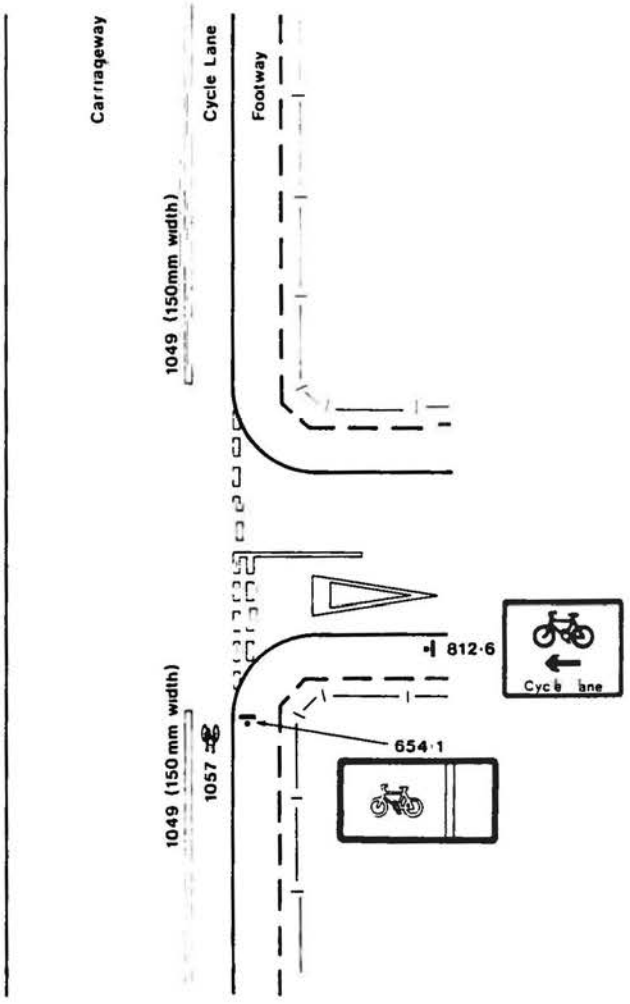


Figure 4.3.1. Typical side-road junction with main road cycle lane.

When a cycle route turns from one road to another at a major/minor junction, a central refuge can often be installed to protect cyclists waiting to complete a right turn. When the turn is at a T-junction, this safeguard is particularly valuable and should always be provided if there is room for it. In other situations, it should be considered whenever the traffic movements make it a likely improvement (2; p. 15 ; 1; p. 210).

4.3.3. *Signalled junctions*

At signal controlled junctions, in addition to the above measures, the signal staging can be altered to cater for cyclists. The introduction of a

stage where cyclists have right of way, or a stage where they have an early start over other vehicles (if they have their own lane and signals), can improve safety. Intergreen periods can also be extended to give cyclists more time to clear the junction (**1**; p. 212).

The separation of traffic movements by signal control gives more protection to cyclists than roundabouts or 'Give Way' signs. A controlled movement affords some protection to right turning cyclists. There may also be a reduction in delay for cyclists, particularly on minor road approaches to junctions, when heavy major road flows can be broken up by signal control (**2**; p. 15).

However, there may remain vehicle movements in a signalled junction that are hazardous for cyclists. At the conventional two stage signalled crossroads the left turning vehicle movement conflicts with the straight ahead cycle movement made from adjacent to the kerb. Also, right turning cyclists have to weave across straight ahead traffic on the approach to the junction. In some cases the levels of flow of individual movements, both motor vehicles and cycles, may suggest the need for a separate signalled phase or stage to assist certain movements and reduce conflicts, though this may cause increased delay to users of the junction and reduce its reserve capacity (**2**; p. 15).

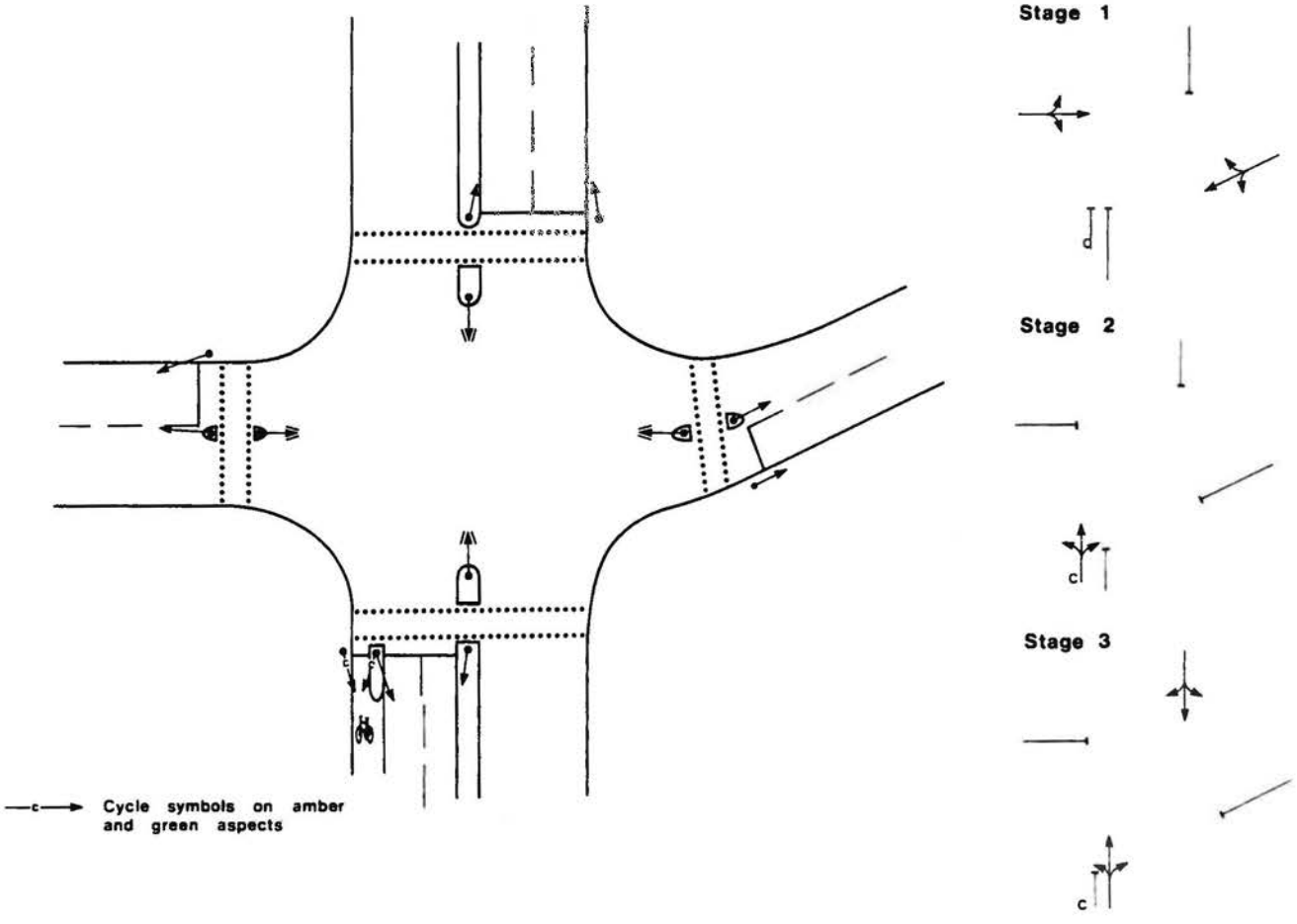


Figure 4.3.2. Cycle lane terminated at signalled intersection by its own separately signalled movement.

Ideally, cyclists should be allowed to move from their own lane using their own phase or stage. Division of the lane from the rest of the carriageway by an island gives physical protection to cyclists and enables the cycle lane to be separately signalled. The lane will usually be at the near (or left hand) side of the carriageway on the approach to the signal installation, and terminated at a separate stopline. The signal aspects for cycles only stages should normally be 210 mm diameter but should have the green and amber lenses masked with a black background to show a cycle symbol. There may be exceptional circumstances where consideration may be given to using 300 mm diameter amber and green cycle aspects and possibly fibre optic systems (**2**; p. 15).

Figure 3.4.2. illustrates a typical site plan for a 4-arm road junction. Suitable signs and carriageway markings should be installed on the approach to the signalled junction to advise of the cycle lane's existence.

In order to reduce delay, movements of other vehicles may be permitted during the cycle phase except where serious conflict between cycle and other traffic streams would arise in the normal signal phasing procedure (**2**; p. 18).

Cyclists' speeds can vary considerably and site constraints should be taken into account in determining a typical speed. However, for signal timing calculations, cyclists' speed is usually assumed to be 4 m/s (15 km/h), from which can be calculated the siting and extension times of loops. The speed assumed also governs the length of the intergreen period following a cycle phase, as cyclists crossing the stop line just as their own green period is terminating must be allowed time to reach a safe position in the junction before the opposing traffic flow begins to move.

When a cycle track is adjacent to a carriageway on the approach to a signalled intersection, care must be taken to ensure that conflicting signals are not visible to vehicles for which they are not applicable. Louvres or long hoods on signal heads may prove useful (**2**; p. 18).

Recently, a study was conducted investigating the operation of expanded bicycle streaming lanes (called 'advanced stop lines' in the UK) at three signalled intersections (**11**). Figure 3.4.3 shows an illustration of the facility. The results showed that most of the motor vehicles and bicylists (more than 75%) made proper use of the facility. At all sites numbers of accidents were low and no statistically significant conclusions could be drawn.

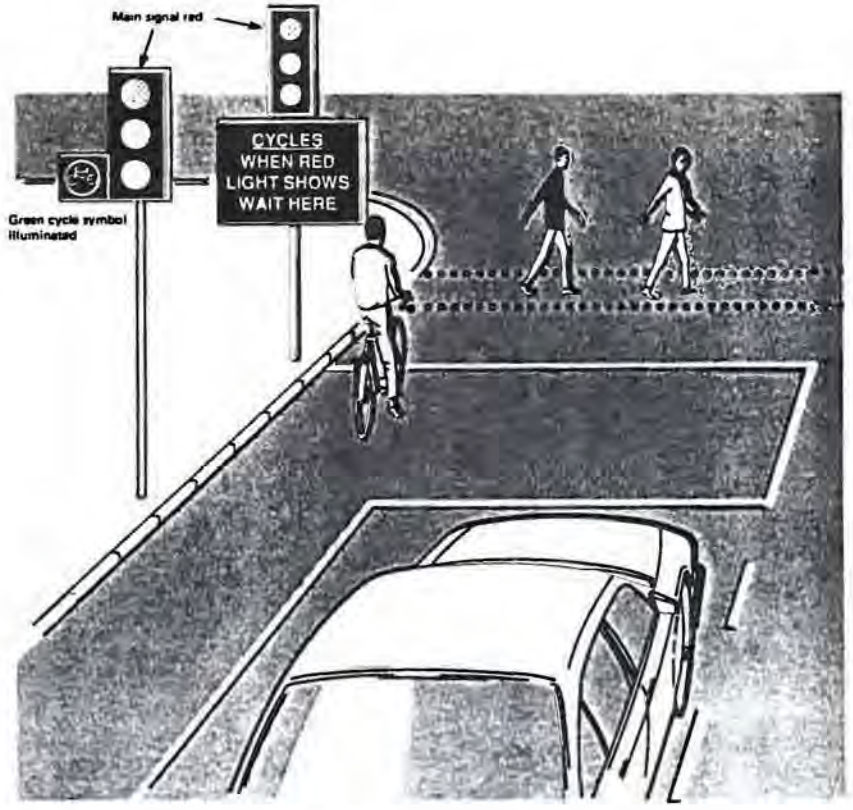


Figure 4.3.3. Illustration of an expanded bicycle streaming lane (also called advanced stop line).

4.3.4. *Roundabouts*

Roundabouts pose particular problems for cyclists. The provision of a cycle lane on a roundabout at the nearside of the carriageway or the conversion of the surrounding footways to joint use by cyclists and pedestrians are possible measures. However, where justified, and subject to space and topography, grade separation can provide a safer alternative (**1**; p. 212). The highway code (**5**) recommends riders to dismount whenever they feel unable to cope with the traffic conditions.

The main conflicts on roundabouts are between cyclists already on the roundabout and motor vehicles either entering or leaving the roundabout. No satisfactory method has been found for reducing the risk to cyclists once they have entered the circulatory system. One attempt to do so was by providing a mandatory with-flow lane on the carriageway on a large roundabout (see figure 3.4.4). Cyclists thought that their journeys had improved, but there was no significant change in the accident rate. The method was tried on a normal size roundabout but was withdrawn because of the absence of any detectable benefit for cyclists (**2**; p. 18).

A cycle route that avoids the junction altogether is one possibility, for example by creating grade separated junctions. If the route is to attract many cyclists from the roundabout, it must not add much to their journey lengths, must be well-signed, and to ensure an effective design the cycling desire lines of the area must be known (**2**; p. 18).

A shorter deviation around the circulatory carriageway of a roundabout may possibly be made by converting the surrounding footways to joint use, as shown in figure 3.4.5. It is less likely to be practicable at an urban roundabout with frontage development and many complex pedestrian movements. An advantage is that the cycle path can be two-way, so that a 270° turn on the roundabout becomes a 90° turn for cyclists. It is attractive to cyclists turning right or left at the junctions, but is less popular with those going straight ahead, as they must give way at the intervening road instead of having priority over it on the roundabout. Alltogether, about half the cyclists using the roundabout are likely to be attracted to such a facility (2; p. 18).

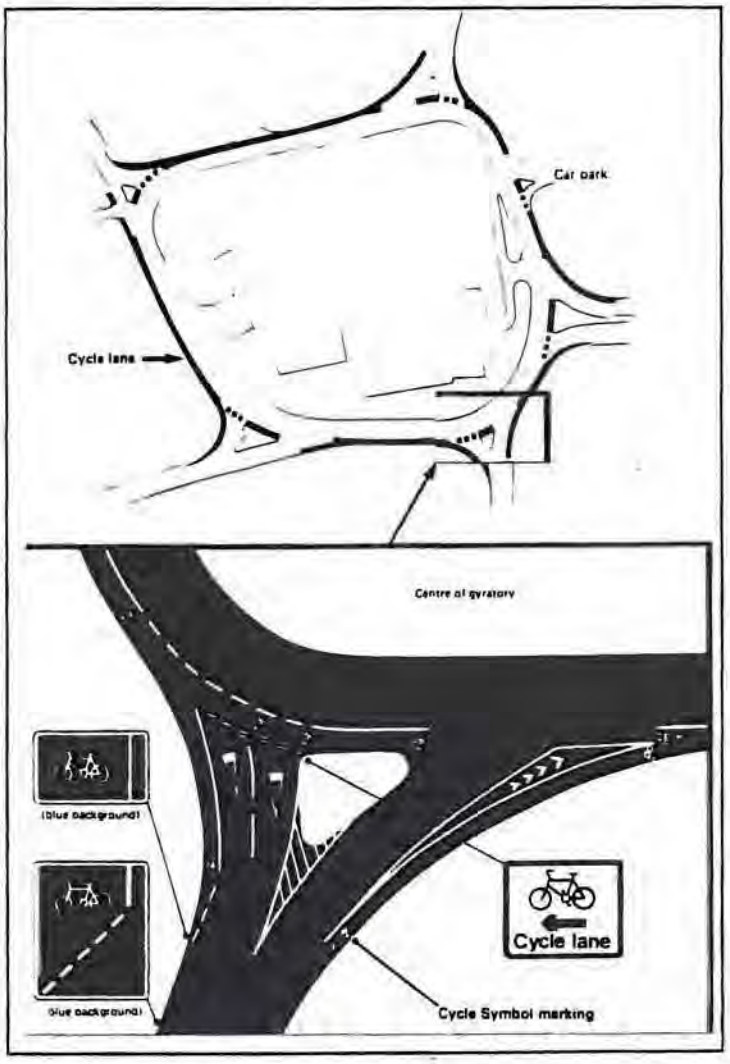


Figure 4.3.4. Cycle lane on roundabout.

A more fundamental way of avoiding the hazards of roundabouts is asking if there should be a roundabout at all. The difficulty is that certain forms of junctions that are safer for 2-wheeled vehicles, such as traffic signals in some circumstances, may be more dangerous for other road users (2; p. 18).

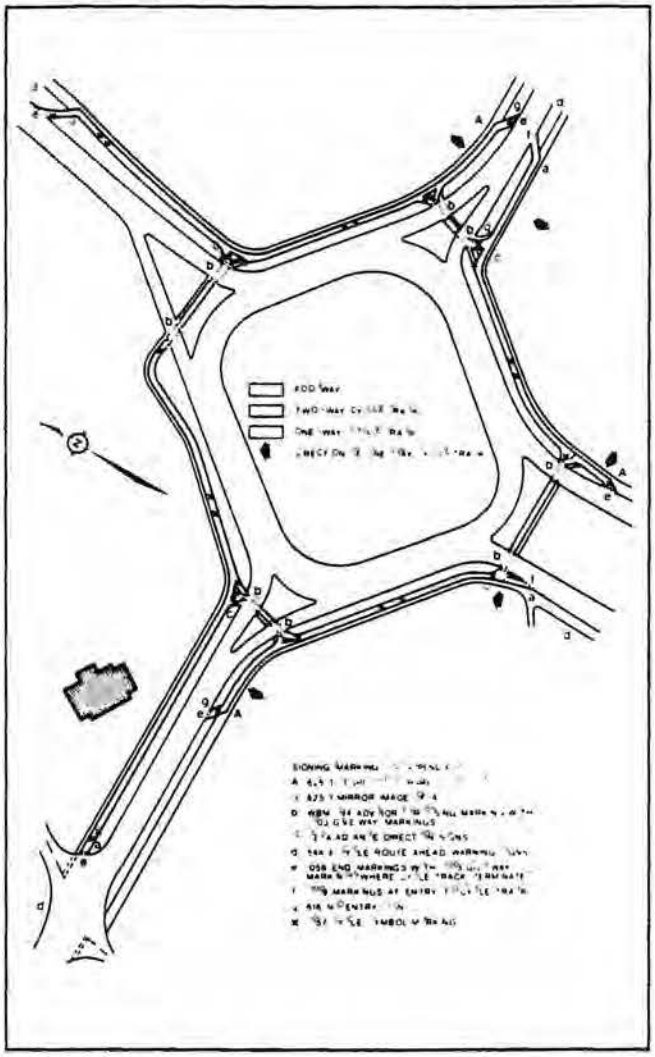


Figure 4.3.5. Peripherical cycle track on roundabout.

4.3.5. *Grade separated junctions*

Grade separated highway junctions are found on many high quality all purpose trunk and principal roads. Traffic speeds are likely to be high for all traffic, whether leaving, joining or remaining on the through route. Where the number of traffic lanes on the route through the junction does not alter, the junctions of the exit and entry slip roads and main carriageway are areas of hazard for cyclists remaining on the through carriageway. At these junctions the slower moving cyclists are at risk, and when cycle accidents do occur, they tend to be serious or fatal. Where the through carriageway at such a junction reduces its number of lanes at the divergence of the exit slip road and/or increases its number of lanes at the merge of the entry slip road, the potential hazards for cyclists on the through route are even further increased (2; p. 21).

The Department of Transport is experimenting with the facility as shown in figure 3.4.6. This provides a diverging lane for cyclists to leave the main carriageway just prior to the end of the entry slip road, and to cross the entry road at right angles and at a crossing point of improved intervisibility. Its disadvantage is that the cyclist has to divert from the direct, straight ahead route, and choose a safe gap in the entering traffic. Nevertheless, it may provide those cyclists willing to use it with the means of avoiding hazards to themselves which otherwise are unavoidable on a route carrying dense flows of high speed traffic, designed without specific provision for cyclists.

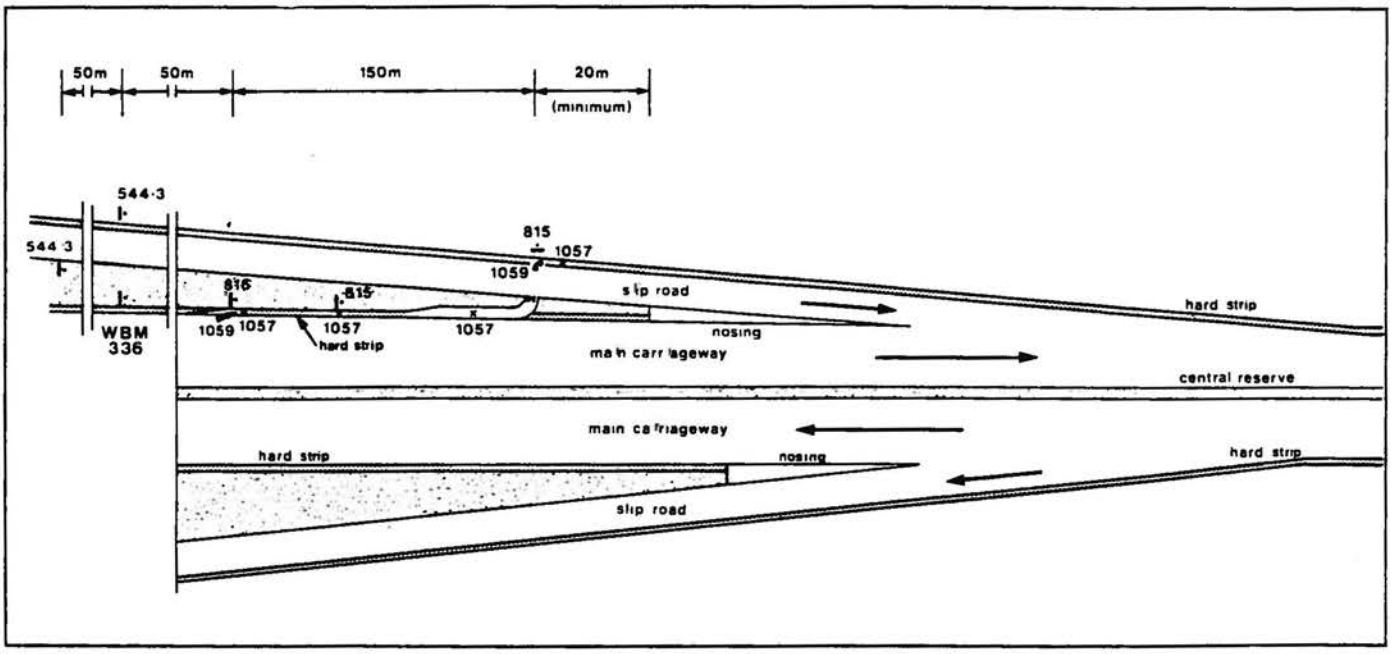


Figure 4.3.6. Cycle facility at a grade separated junction.

A similar 'mirror image' scheme on exit slip roads whereby the cyclist leaves by the slip road and crosses it at right angles to return to the through carriageway is possible. It may not, however, be suitable where intervisibility for cyclists and vehicle drivers is poor and warning signs are difficult to site effectively.

Though the experimental sites are few in number, the indications are that they can result in a reduction in cycle accidents. They appear to have no measurable effect on non-cycle accidents. Such a solution is relatively low cost, and even where small numbers of cyclists are involved the technique may offer high rates of return at sites with a poor cycle safety record (2; p. 21).

4.4. Bibliography

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5. Germany

5.1. General rules for bicyclists

Bicyclists have to comply with the behavioural rules just as other road users. These are laid down in the so called 'Straßenverkehrs-Ordnung StVO'. In addition to the behavioural rules that apply to all road users, specific rules for bicyclists exist. Some of them, which are relevant to this chapter, are:

Bicyclists must use bicycle tracks or bicycle lanes on the right side of the carriageway, if present, and if these are indicated by the special 'bicycle' roadsign. In the case of lanes (as opposed to separate tracks) this road sign must be repeated at every intersection. Bicycle tracks or lanes on the left side of the road can only be used by bicyclists if they are indicated by means of a road sign as two-way bicycle tracks or lanes. Other road users are not allowed to use these facilities. This also applies to electrically assisted bicycles that can not exceed a speed of 25 km/h, except when an additional roadsign indicates that also faster types of bicycles or mopeds can make use of the bicycle facility. In the absence of special bicycle facilities, bicyclists should make use of the hard shoulder at the right side of the carriageway, if present. Shared facilities for bicyclists and pedestrians inside built-up areas can, in principle, only be considered when mopeds or other electrically assisted bicycles are not allowed to use them (**1**; p.8-9).

5.2. Status of standards for bicycle facilities

The guidelines that have been used for this chapter are *recommendations* for bicycle facilities at intersections (**1**). Most recommendations apply to both inside and outside built-up areas. Par. 5.4 summarizes explicit recommendations for bicycle facilities outside built-up areas. No compulsory standards exist with regard to bicycle facilities at intersections. Standards exist for behavioural rules, traffic signs, markings etc. in general, but not for specific bicycle facilities.

5.2.1. *General (road safety) considerations*

In order to create traffic flows that are as safe as possible, bicycle facilities at intersections should meet the following requirements (**1**; p. 51):

- safe separation of bicycles and other traffic;
- clear guidance of bicycles over the intersection, both for bicyclists themselves as well as for other road users;
- comprehensive priority regulations between bicyclists and other road users;
- good sight conditions between bicyclists and other road users.

Maintaining the quality of the bicycle facilities that are already present at the cross sections leading to the intersection should be strived for, when designing bicycle facilities at intersections. Under no circumstances should bicycle facilities end abruptly at the intersection. On the other hand, due

to safety considerations, the application of streamed bicycle tracks or bicycle lanes can be considered at intersections even when no such facilities are present at prior cross sections. Facilities that are only applied at or near an intersection serve to guide bicyclists over this dangerous area, and emphasize their (possible) passage to other road users (**1**; p. 49).

5.3. Bicycle facilities at intersections

5.3.1. *Basic forms of bicycle facilities at various types of intersection*

Figures 5.3.1 and 5.3.2 present a schematic overview of basic solutions for bicycle facilities at various types of intersections. It should be noted that the way in which the rows in the figures are ordered does not imply preference for certain solutions or recommendations over others as regards content (**1**; p. 55). In every situation, depending on local circumstances, it should be attempted to choose the facility that is optimal for both bicycles and the interest of other road users (**1**; p. 57). A number of facilities will be discussed in more detail in the following paragraphs.

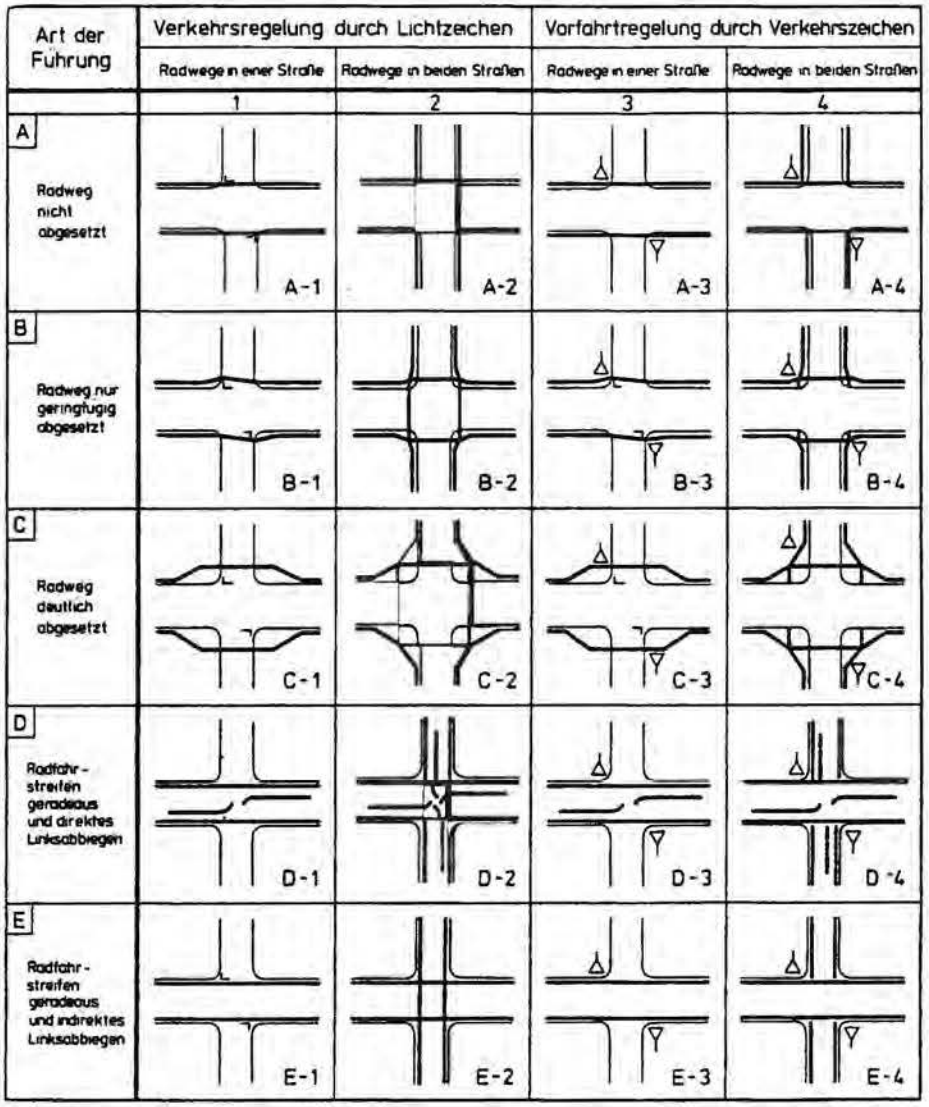


Figure 5.3.1. Overview of basic forms of bicycle facilities at 4-armed intersections.

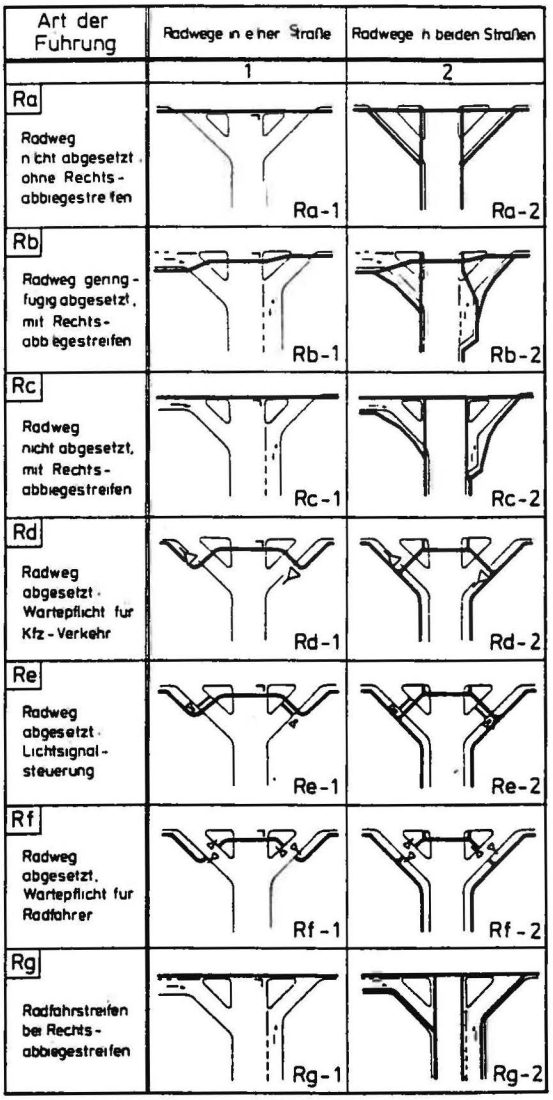


Figure 5.3.2. Overview of basic forms of bicycle facilities at triangular-island intersections.

5.3.2. *Direct or indirect left-turns*

A direct left turn for bicycles can be considered when at the cross section leading to the intersection no separate cycle tracks are present; when cycle tracks are transformed into cycle lanes at or just before the intersection, or when urgent reasons exist to end cycle tracks at the intersection (**1**; p. 51).

Out of road safety considerations a direct left turn for bicyclists can only be considered when it is easily possible for bicyclists to pull over to the left. This is the case when motor vehicle volumes are low, the allowed speed for motor vehicles is 50 km/h or less, only one lane for motor vehicles going straight ahead is present, or when signal controlled turning lanes for bicycles are present (**3**; p. 295). Outside built-up areas specific markings or turning lanes for direct left-turning bicycles are never recommended (**1**; p. 51).

Indirect left turns for bicycles can always be recommended when at the cross section leading to the intersection cycle tracks are present. Also, if no cycle tracks are present, an indirect left turn is recommended when a

direct left turn is considered too dangerous (**1**; p. 51). Direct and indirect left turns are illustrated in figure 5.3.3.

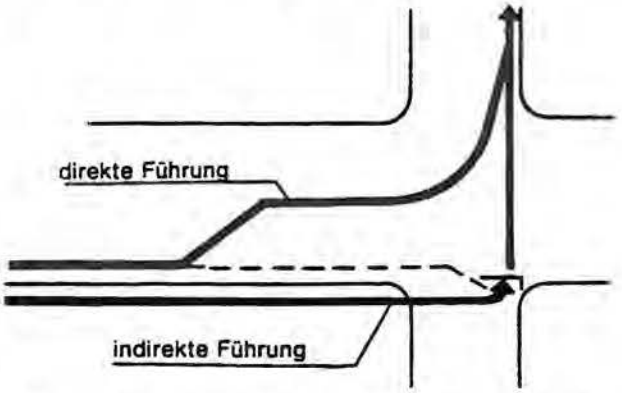


Figure 5.3.3. Possibilities for direct and indirect left turns.

Clear guidance of left turning bicycles is necessary. For indirectly left turning bicycles safe and sufficiently large areas should be applied enabling riders to wait before crossing to the left. When these areas are located on the carriageway it is recommended that they are announced by signs. These signs are not official road signs, but information signs (see figure 5.3.4). Areas as shown in figure 5.3.5 should also be present on two-way bicycle tracks/lanes (**1**; p. 57).

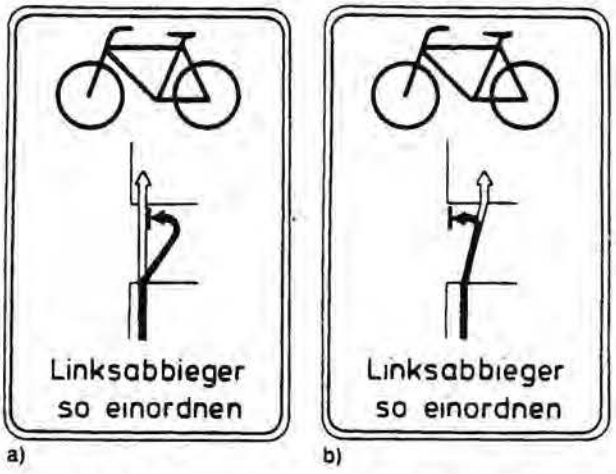


Figure 5.3.4. Information signs for indirect left turning bicycles indicating waiting areas located (a) at the right, and (b) at the left of the cycle way.

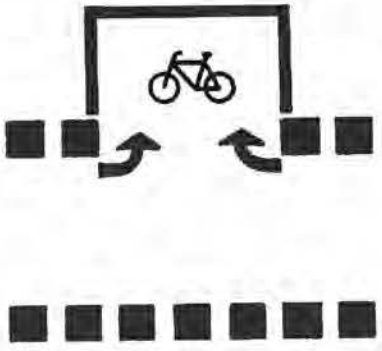


Figure 5.3.5. Waiting area for indirect turns along two-way cycle tracks/ lanes.

5.3.3. *Bending-out or not*

At intersections with priority signs, cycle tracks are generally not bent out from the carriageway which has right of way (see figure 5.3.6). In this way it is clear to drivers of vehicles, entering from the side-road, that bicyclists riding on the main road have priority. This also holds for turning traffic from the main road. Uncertainty about the desired direction (straight ahead or turning right) of the bicycles is avoided. On the other hand, the design of such cycle track can cause motor vehicles waiting to enter the intersection from the side-road to block the cycle track (**1**; p. 52).

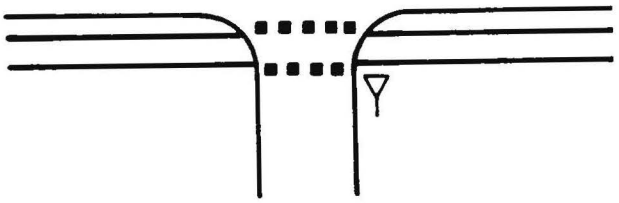


Figure 5.3.6. Illustration of cycle track which is not bent-out.

When bicycles are recommended to turn left indirectly, the cycle track should be bent-out slightly as shown in figure 5.3.7, which give left turning bicyclists some room for waiting (**1**; p. 52).

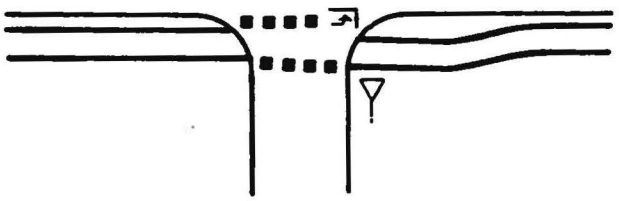


Figure 5.3.7. Illustration of a slightly bent-out cycle track.

When sufficient room is available, cycle tracks can be bent-out more clearly (4-6 m; see figure 5.3.8a). This is recommended particularly at intersections which are not signal-controlled, and when it is important that turning vehicles from the main road do not interfere immediately with bicyclists crossing the side-road. A disadvantage of such bent-out cycle tracks is that vehicle drivers will possibly not recognize that they have to give right of way to bicycles (**1**; p. 52). Therefore, this solution is not recommended at intersections where many motor vehicles turn right. Bending out should take place gradually well before the intersection. A sharp, abrupt bend should be avoided; this can cause right turning motor vehicles to ignore the right of way of crossing bicycles (**1**; p. 62-63).

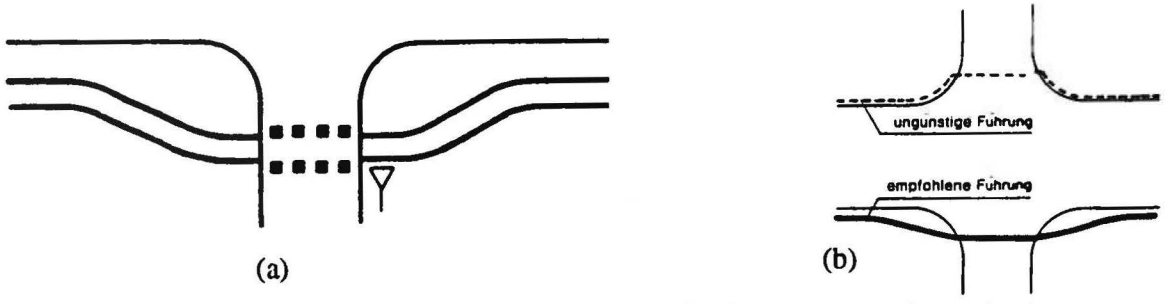


Figure 5.3.8. (a) Illustration of a clearly bent-out cycle track; (b) recommended (solid line) and non-recommended (dashed line) design.

Recent research (2) has indicated that for bicyclists going straight ahead at intersections without signal control, clearly bent-out cycle tracks (> 4m) are less advantageous from the viewpoint of safety than those spaced closer to the edge of the carriageway. However, at such clearly bent-out cycle tracks cyclists are seldom hindered by turning vehicles blocking their view. Sight obstructions of this nature are particularly frequent with a bending-out between 2 and 4m.

5.3.4. *Streamed cycle tracks*

Streamed bicycle tracks can be recommended when not sufficient room is available to construct bicycle facilities at cross sections leading to large, busy intersections, whereas at the intersection itself possibilities exist to guide/conduct bicycles across the intersection separately from other road users. Streamed bicycle tracks begin shortly before the intersection and generally end about 20-50 m behind the intersection (1; p. 49).

5.3.5. *Weaving*

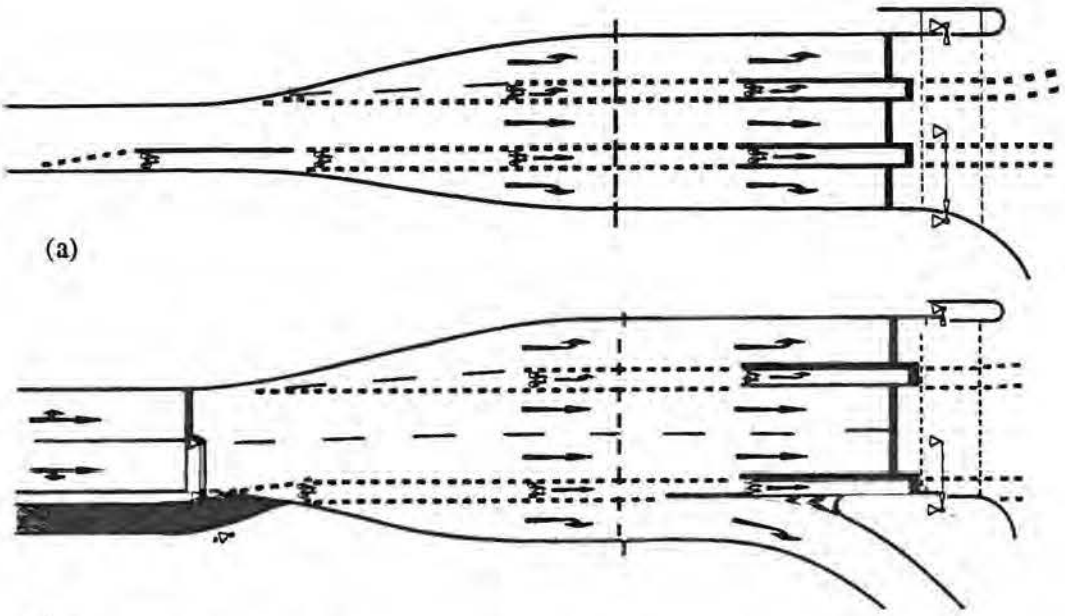
Weaving the bicyclists with the other road users into specific lanes is another possibility when guidance is needed for bicycles to cross the intersection. This facility is recommended when cycle lanes are present at the cross section leading to the intersection, or when no cycle facilities are present there but guidance is considered necessary, and when it is not possible to apply (streamed) cycle tracks (1; p. 68).

Research has indicated that bicyclists going straight ahead at intersections with a high risk potential often have a lower accident risk when they ride on the carriageway or on a cycle lane as compared to when they arrive at the intersection riding on a cycle track (2, 4). Under these circumstances weaving lanes can be a solution.

A bicycle lane for bicycles going straight ahead is situated at the right side of the lane for motor vehicles going straight ahead. (When no separate lane for right turning motor vehicles is present, this bicycle lanes is also used by right turning bicyclists.) Left turning bicyclists are usually guided directly to a special left-turn lane. These bicycle lanes allowing bicyclists to weave with the other road users should begin before the left- and right-turn lanes for motorized traffic start. Such lanes can also be applied when bicyclists are led from cycle tracks that are present at the intersection approach. In this case it is allowed to apply bicycle weaving lanes when more than one lane for motor vehicles going straight ahead is present. The transition from bicycle track to bicycle lane should take place at least 50 m before the intersection (1; p. 69).

Research has shown that weaving lanes that are *painted red* are safer for bicyclists going straight ahead than weaving lanes which are merely indicated by markings on a non-differential surface colour (3). *Differentially surfaced* bicycle crossings appear to be particularly safe (2).

Weaving lanes can usually be found at signalled intersections (see par. 5.3.7). Figures 5.3.9 (a) and (b) show illustrations.



(a)

(b)

Figure 5.3.9. Illustrations of weaving when: (a) no cycle facilities are present at cross section before intersection and (b) when a cycle track is present at cross section before intersection.

5.3.6. *Two-way cycle tracks*

When it is allowed for bicyclists to ride along cycle tracks in both directions, this should be clearly indicated. At intersections with priority rulings by means of signs it should be verified that motor vehicles from the side-road are warned for bicycles riding in 'the wrong direction' to which they have to give way. This is particularly important when it is difficult to gain a clear view of the track and/or the bicycles riding on it (**1**; p. 57). Drivers of vehicles can, for example, be informed of a two-way cycle track by means of the sign as shown in figure 5.3.10 (see also par. 5.3.2).

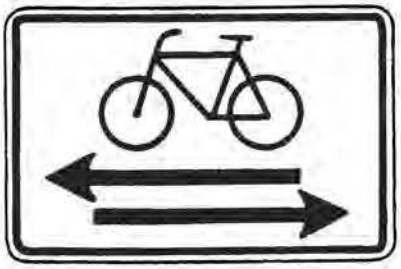


Figure 5.3.10. Example of an informational sign for drivers of motor vehicles to indicate the presence of a two-way cycle track.

5.3.7. *Signalled intersections*

Separate traffic lights for bicyclists have the advantage that the clearance times can be adjusted to the speed of the bicyclists. When such traffic lights are situated next to those for motor vehicles, they also serve as a reminder for drivers of motor vehicles to expect bicyclists at the intersection (**1**; p. 60).

A distinct stop-line for bicycles, about 2 m before the stop-line for motor vehicles, allows bicyclists to be in the sight of drivers of motor vehicles when they wait for the traffic light (**1**; p. 60).

If possible, bicyclists cross the intersection before the traffic island in the road to be crossed (see figure 5.3.11). Only when it is considered absolutely necessary for bicyclists to cross the intersection through the traffic island, this may be done. Because the traffic island is used to place equipment (e.g. traffic lights) this design practice is, in general, not recommended (**1**; p. 60).

Research has indicated that at signal controlled intersections the safety of bicyclists going straight ahead is often better when they ride on the carriageway or cycle lane than on cycle tracks along the road, since the important conflict with right turning motor vehicles occurs less often in these cases. At signal controlled intersections it will therefore be advisable to often convert bicycle tracks into bicycle lanes at the approaches to the intersection (cf. weaving, par. 5.3.5).

At all locations where bicyclists cross signalled intersections this should be clearly marked by means of block-markings painted on the road (as indicated in figure 5.3.11, for example). *These markings should also be applied at all other crossings where bicyclists have priority over other road users. On the other hand, at locations where bicyclists should give way to motor vehicles no such markings should be employed* (**1**; p. 56).

Recent research findings show that especially markings of a differential surface are safer than other types of marking on the road (**2**).

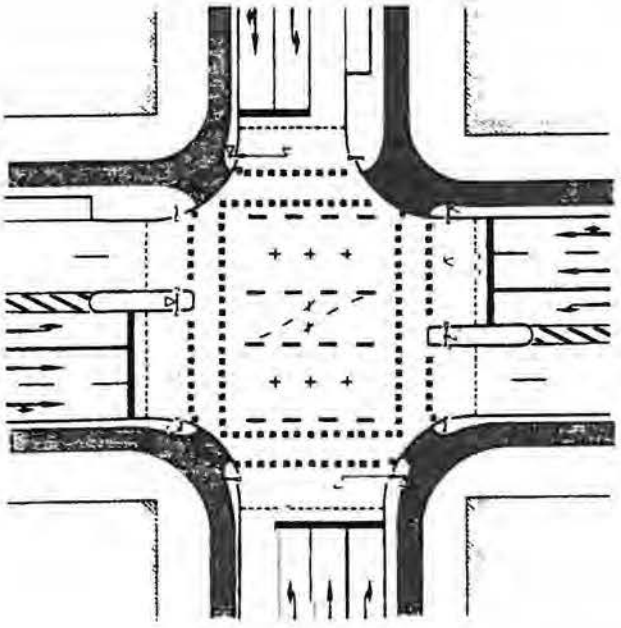


Figure 5 3.11. Example of cycle facilities at a signal controlled intersection.

5.3.8. *Triangular islands*

Intersections with so-called 'triangular islands' or 'right turn bays' (Germ.: Dreiecksinseln) are usually considered to be very dangerous for bicyclists, because of the generally high speeds of motor vehicles. When triangular islands are present, several basic solutions for bicycle facilities can be distinguished (see for an overview figure 5.3.2). When designing new intersections of this type, it is recommended to apply traffic lights to help bicyclists cross the intersection safely (**1**; p. 64). Research has shown that accidents between right turning vehicles and bicyclists continuing straight ahead at this type of intersection are considerably more frequent when no traffic lights are present as compared to situations where the right turning traffic is controlled by signals governing traffic movements at the intersection (**2**).

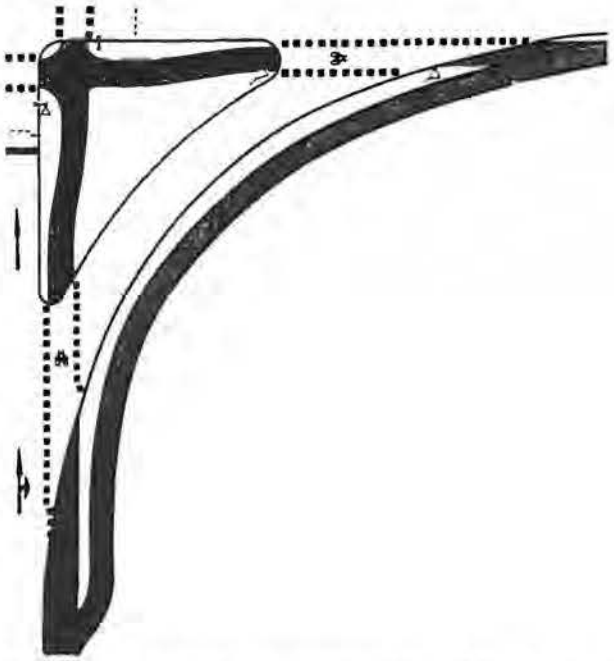


Figure 5.3.12. Example of triangular island with cycle tracks which are not bent-out; bicycles have priority over motor vehicles.

For triangular islands *inside built-up areas* it is, in principle, recommended that bicycle tracks are not bent-out (see figure 5.3.12; cf. solutions Ra-Rc and Rg in figure 5.3.2). Such bicycle tracks are considered to have the advantage over bent-out cycle tracks in the sense that the former will lead to a better understanding that bicyclists should be given right of way (**1**; p. 64). Research has shown that bicycle tracks whose crossings are closely spaced to the beginning of the right turn bay are most favourable from the viewpoint of safety and should therefore be the preferred solution (**2**).

For triangular islands *outside built-up areas* bicycle tracks are, in principle, recommended to be bent-out (see par. 5.4 for more detail).

5.3.9. *Roundabouts*

At large roundabouts, the number of bicycle accidents is very high compared to the number of such accidents at other intersection designs. In urban areas, such forms of intersection are in most cases not compatible

with bicycle traffic unless grade separation for bicycles is possible. The results of an accident analysis are generally more favourable for the bicycle traffic on the carriageway than on bicycle lanes or tracks. The use of bicycle tracks depends on the bicycle facility on the road stretches leading to the roundabout and the most important routes taken by bicycles across the roundabout (two-way bicycle traffic) (2).

5.3.10. *Sight*

It is important that bicyclists and drivers of motor vehicles can see each other at intersections. The view/visibility of the bicycle facilities should be guaranteed at sufficient distance before the intersection (1; p. 56).

This principle is considered particularly important at those situations where right turning motor vehicles and bicycles going straight ahead can meet each other, because many accidents result from this type of conflict. For the same reason it is important to create a clear view at situations where bicycle tracks or bicycle lanes are located directly at the right side of parkinglanes. At intersections where two-way cycle tracks are present sufficient sight should be created in order to enable that left turning motor vehicles and bicycles riding on the left sided bicycle track see each other (1; p. 56).

Figure 5.3.13 shows an example of a 'sight-triangle' which reflects the area that should be kept 'free'. In calculating the sight-triangle the speed of the motor vehicles should be taken into account, as well as whether or not the bicycles have priority over the motor vehicles on the road to be crossed. In figure 5.3.13 the sight-triangle is shown for the case in which the bicycles have priority over the motor vehicles on the road to be crossed, and the speedlimit on that road is 50 km/h (1; p. 10).

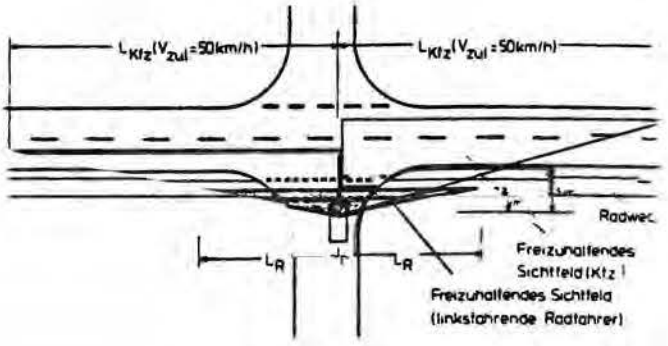


Figure 5.3.13. Example of a sight-triangle to ensure that bicyclists and drivers of motor vehicles can see each other.

5.4. Bicycle facilities at intersections outside built-up areas

In general, the recommendations and principles formulated in the previous paragraphs also hold for intersections outside built-up areas. In this section specific recommendations for bicycle facilities at intersections outside built-up areas are summarized (**1**; p. 70).

For several reasons it is particularly important that bicyclists and drivers of motor vehicles can see each other, and that priority rulings are comprehensible at intersections outside built-up areas: because outside built-up areas
(1) speeds of the motor vehicles are generally high;
(2) bicycle facilities are usually one-sided two-way cycle tracks (often shared with pedestrians);
(3) bicycles are not often encountered, so drivers of motor vehicles don't expect them.

Bicycle lanes, and in particular those for directly left turning bicycles, are *not* to be recommended at intersections outside built-up areas (**1**; p. 70)

In previous paragraphs it was recommended that cycle tracks should, in principle, not be bent-out. An exception to this rule is a non-signalled intersection without triangular islands outside built-up areas. At intersections of this type bent-out cycle tracks can be recommended (**1**; p. 52). Particularly basic solutions of form C (see figure 3.5.1) - with clearly bent-out bicycle tracks - are recommended outside built-up areas. An illustration of the basic form C-3 is shown in figure 5.4.1. Note that the bicyclists are guided through a traffic island in the road to be crossed.

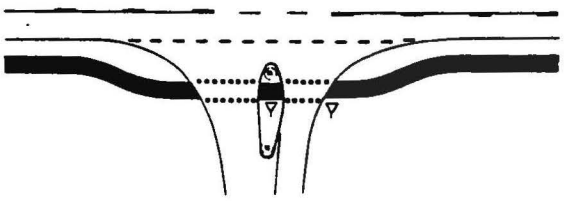


Figure 5.4.1. Example of basic form C-3 at an intersection outside built-up areas with clearly bent-out track and right of way for bicycles.

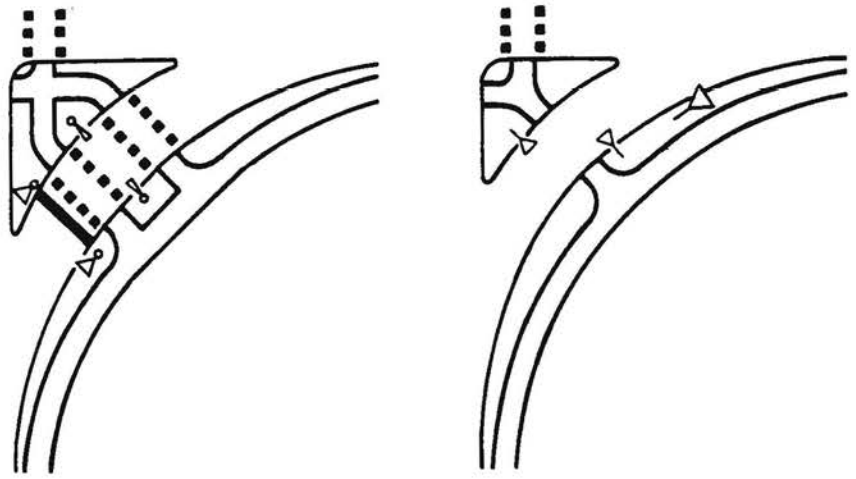
In exceptional cases the priority ruling can be reversed at intersections outside built-up areas, i.e., the bicyclists riding on the cycle track along the main road should in those cases give way to motor vehicles from the side road. This can be done, for example, when only few bicycles can be encountered at the cycle track while the side road is heavily used. When reversing the priority ruling, the cycle track should be bent out strongly (**1**; p. 72).

Also at intersections with triangular islands it is recommended to apply bent-out bicycle tracks. This can be done in three ways (**1**; p.53):

(a) right of way for bicycles (cf. basic form Rd in figure 3.5.2); this solution is *not* recommended for situations outside built-up areas;
(b) include bicycles in the signal control; see figure 5.4.2.a (cf. basic form Re in figure 3.5.2);

(c) adjust the priority regulation in such a way that bicycles have to give way to motor vehicles; see figure 5.4.2.b (cf. basic form Rf in figure 3.5.2).

Solution (c) is recommended in particular for this type of intersection outside built-up areas; the bicycle track should be bent-out at least 2 m to enable that bicyclists and drivers of motor vehicles can see eachother (1; p. 67). Right of way for bicycles over right turning motor vehicles is, in general, *not* recommended at this type of intersections outside built-up areas (1; p.70).



(a) (b)

Figure 5.4.2. Bent-out bicycle tracks at intersections with triangular islands: (a) with signal control; (b) bicycles have to give way to motor vehicles.

Intersections without cycle tracks or cycle lanes

When it is not possible (e.g. lack of space) to apply bicycle tracks or bicycle lanes it is recommended to apply facilities at the intersection that enable bicyclists to turn left indirectly (1; p. 72).

At signalled intersections it is recommended that bicyclists can cross the intersection in one time. When, in exceptional cases, it is necessary to create a stop 'halfway' short waiting periods for bicyclists should be employed. The situation where bicyclists have to wait on a traffic island can, for example, occur when separate phases for traffic in opposing directions are applied on the main road. Traffic lights should, if possible, be adjusted in a conflict-free manner (1; p.74).

5.5. Bibliography

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* New guidelines for bicycle facilities are in preparation, and will probably be released in 1994.

6. Comparison between countries and conclusions

This report provides an overview of standards for bicycle facilities at intersections which exist in a number of EC-countries. It turned out that only four countries appear to have specific documentation on this subject: Denmark, The Netherlands, United Kingdom, and Germany. The previous chapters summarized the available standards for these facilities in the respective countries. The reason that other EC-countries do not have specific standards for bicycle facilities at intersections is most probably related to the fact that the bicycle as a means of transport in these countries is (still) a rare phenomenon. The presented overview, however, might offer some help to those countries that intend to prepare such standards in the future.

Status of the standards

The various 'Highway Codes' in the countries under consideration have compulsory status, and regulate behavioural rules for road users, including bicyclists. Also, specific traffic signs to indicate bicycle facilities that can or must be used by bicyclists usually have compulsory status, although often additional informational (non-compulsory) signs are used to draw attention to facilities for bicyclists. Furthermore, markings on the road to indicate that bicyclists can or must use a facility at an intersection, such as the presence or absence of broken lines and cycle symbols painted on the road, are generally of a compulsory nature. However, *design standards for specific bicycle facilities, or 'solutions', at intersections as reviewed in this report are generally non-compulsory guidelines and recommendations*. Therefore, the terms guidelines and recommendations describe their status better than the term 'standard' might imply.

In general, the guidelines may be deviated from, or relaxed, if considered 'appropriate'; these can then be called recommendations. Other guidelines may only be deviated from when grounded motivations are supplied. In all countries concerned, procedures exist that must be followed when one wants to deviate from the guidelines. In the Netherlands, for example, the various types of 'standards' are explicitly distinguished, and it is indicated in the documents themselves whether described facilities are guidelines or recommendations. However, for the other countries it is not always clear from the documents reviewed whether the described facilities are mere recommendations or more strict guidelines.

In Denmark and The Netherlands different guidelines and recommendations exist for bicycle facilities at intersections inside built-up areas and outside built-up areas. In Germany most, and in the United Kingdom all guidelines and recommendations apply to both inside and outside built-up areas.

Role of road safety considerations

Although road safety considerations as a criterion for establishing guidelines and recommendations for bicycle facilities at intersections are considered 'important' in all countries, it has to compete with other criteria such as traffic flow and comfort. It is often not clear to what extent road safety played a role: was road safety the most important

criterion or did other criteria have priority over safety? So, whereas 'globally' road safety is considered an important criterion, the guidelines lack explicit clues that justify specific (elements of) bicycle facilities over others.

In general, it appears that no strong safety evidence is to be found in the guidelines themselves. The guidelines mention no explicit references to research findings. So, even if guidelines state that 'out of road safety considerations' a certain facility is recommended it is often not clear whether this is based on assumptions or on empirical evidence. And if this type of data exists or has been used as a basis for the guidelines, it is still not cited in the guidelines. Although the Danish guidelines also do not refer to research findings, it appears that in Denmark the term 'safety' may only be mentioned in the guidelines if research findings have indicated this (Kjemtrup, 1994; personal communication).

To illustrate that at least some of the guidelines and recommendations are based on empirical evidence, some research references have been added in the various chapters. These references were supplied by researchers in the four countries concerned. It should be noted that they do not represent a complete list of available research. Since the main objective of the project was to summarize the standards for bicycle facilities at intersections, the research findings just serve as illustrations. The general impression is that safety assessments of specific cycle facilities at intersections based on accident data are scarce - and, if available, often too few accidents occur at the sites under investigation to reliably measure safety effects. Usually these studies also include behavioural observations on the use of some specific bicycle facilities at intersections, and on occurring conflicts between bicyclists and other road users.

Definitions

The usage of terms for bicycle facilities in the guidelines varies between countries. For example, what is called a cycle path in one country can mean a cycle track and/or a cycle lane in another. "Harmonization" of terms would be clarifying when reading guidelines of different countries. In this report we have attempted to use terms in a consistent manner. For instance, the term *cycle track* is used when this cycle facility is separated from the carriageway by a narrow dividing verge or by kerbstones; the term *cycle lane* refers to a part of the carriageway which is meant to be used by bicyclists, and is indicated by markings or painted lines on the road surface, and the term *cycle path* is only used for separate cycle tracks with an own alignment (away from roads).

Common principles and 'solutions'

Creating *good sight conditions* is mentioned in all guidelines as being an important principle or (safety) criterion. The visibility of the bicycle facilities should be guaranteed at sufficient distance before the intersection. This can be accomplished by creating an area that should be kept free from obstacles that can block sight. In Denmark it is generally recommended that at intersections bicycles should be close to motor vehicles, otherwise they will be overseen. In order to attain this a bicycle track often becomes a bicycle lane 25 m before the intersection (Kjemtrup 1994; personal communication). Therefore, the bending out of cycle tracks is, in principle, not recommended in Denmark, although exceptions are

possible and the Danish guidelines contain recommendations for the bending out of cycle tracks in case these are applied.

At intersections with priority signs, cycle tracks are generally not bent out from the carriageway which has right of way. In this way it is clear for drivers of motor vehicles from the side road that bicyclists on the main road have priority. This also holds for turning traffic from the main road. *Bending out is usually recommended at intersections which are not signal controlled, and when it is important that turning motor vehicles from the main road do not interfere immediately with bicyclists crossing the side road. This solution is typically recommended outside built-up areas.* It can be accompanied by reversing the priority rules.

In general, *both priority rulings and design* are important factors to consider at intersections. *Which priority ruling is 'better' or 'safer' is still under discussion.* In Germany, for instance, reversing of priority rulings for bicyclists at intersections (i.e. that bicyclists have to give way to other traffic instead of having priority over other traffic) is, in principle, not recommended, not even outside urban areas. In the Netherlands, however, reversing the priority rulings is often recommended outside built-up areas, usually in combination with the application of bent-out cycle tracks at intersections. Reversing priority rulings is - under certain conditions - also to be found in the UK-guidelines.

Refuges or *traffic islands* in the road to be crossed allow bicycles to cross in stages. Such facilities are often recommended when bicyclists do not have right of way.

The *separation* of bicyclists from other traffic, either physically or visually, is a criterion that is also mentioned in all guidelines. Physical separation can be accomplished by applying grade separated junctions or separate cycle paths with their own alignment. Because it is often not possible to create such facilities (e.g. due to lack of space) applying cycle tracks is a common 'solution'. *Streamed cycle tracks* are often recommended when no sufficient room is available to construct bicycle facilities at cross sections leading to (large, busy) intersections, whereas at the intersection itself possibilities exist to guide bicycles across the intersection separately from other road users. Streamed bicycle tracks begin shortly before the intersection and generally end about 20-50 m behind the intersection. Visual separation refers to cycle lanes which are indicated by painted markings and lines on the carriageway. Whatever solution is chosen, *clear markings and signs* indicating where bicycles can cross the intersection, are in all guidelines considered important to increase the safety of bicyclists.

The recommendation of certain facilities over others also depends on the *speed and volume of motor vehicles.* Research has indicated that mixing bicycles with motor vehicles at intersections is sometimes even safer than bicycles on cycle tracks. For instance, in most guidelines, mixing bicycles with other traffic is recommended in situations with low speeds and low volumes of motor vehicles. Again, clear markings should indicate where bicyclists can be encountered. *Weaving lanes* are often recommended when guidance is needed for bicycles to cross the intersection, and when cycle lanes are present at the cross section leading to the intersection, or

when no cycle facilities are present there but guidance is considered necessary. Weaving lanes for bicycles can, for instance, prevent conflicts between right turning motor vehicles and bicycles going straight ahead. To enhance this effect it is often recommended to paint such lanes in a *different colour*, or apply *differentially surfaced* bicycle crossings.

Indirect left turns for bicyclists are usually recommended when at the cross section leading to the intersection cycle tracks are present. Also, if no cycle tracks are present, an indirect left turn is often recommended when a direct left turn is considered too dangerous. It should be realized, however, that indirect left turns should actually be used by bicyclists in order for them to be safe. When indirect left turns take a lot of time, and motor vehicle speeds and volumes are low, bicyclists often neglect the indirect left turn facilities (see e.g. Twisk & Hagenzieker, 1993). In these cases weaving lanes allowing bicyclists to turn left directly can be preferred.

Traffic lights can be applied out of safety considerations for bicycles. However, most guidelines recommend in some way or another that, if possible, the need to apply traffic lights should be avoided by adjusting the intersection in another way. When traffic lights are applied it is usually recommended that traffic light installations are regulated conflict-free, that waiting time is short, that there is a general bicycle phase (i.e. while bicycles are offered green, all other traffic is given a red phase), and that the stage order is friendly for the cyclists. With regard to possible conflicts between bicycles going straight ahead and motor vehicles turning right, an early start may be recommended. In addition, the guidelines often recommend a separate facility in which cyclists can turn right regardless of the traffic-light regulation.

At intersections with mixed traffic or visual separation, weaving, refuges or special *waiting areas* for bicyclists are facilities that are often recommended. In the Netherlands so called expanded bicycle streaming lanes that consist of a separate streaming facility for cyclists in front of the streaming spaces for motorized traffic, and of an accompanying approach cycle lane, are recommended at signal controlled intersections. It creates a waiting area for bicyclists; they are often accompanied by an early start for bicyclists at signal controlled intersections. Experimental application of such facilities in the United Kingdom - although these are not to be found in the guidelines (yet) - show positive results in terms of safety and correct usage.

With respect to *roundabouts* no conclusive findings (from research conducted in Denmark and The Netherlands) exist in order to decide between mixing bicycles with other road users, applying cycle lanes or cycle tracks in the circulation area of roundabouts. The various guidelines, therefore, usually contain recommendations for all types of bicycle facilities as possibilities. Whereas the experience in Denmark and the Netherlands indicates that roundabouts are relatively safe for bicyclists as compared to other types of intersections, the United Kingdom-guidelines state that roundabouts pose particular problems for cyclists. The particular design and lay-out of roundabouts, which varies between countries, obviously has implications for the safety of cyclists, and for that reason, also for the bicycle facilities that can be recommended.

From the previous paragraphs it becomes apparent that besides common principles and recommendations, differences are also encountered between the guidelines of the various countries. It appears that there are sometimes strong differences in the matter of detail in which the guidelines are described between the various countries, and also the guidelines themselves differ between countries. This probably has to do with the fact in Germany and the United Kingdom relatively few bicyclists are present in traffic, whereas in Denmark and The Netherlands the bicycle is a common means of transport. This obviously has implications for both the experienced need for separate guidelines for bicycle facilities at intersections in the different countries as well as for their contents. For instance, in Germany and the United Kingdom facilities are often shared by bicyclists and pedestrians, whereas such facilities are seldom applied in Denmark and The Netherlands. Therefore, guidelines for 'shared use' are to be found in the guidelines of the former two countries but not in the latter two. In addition, the application of cycle tracks and cycle lanes varies between countries; for instance, in the United Kingdom cycle tracks are hardly present, whereas in the other countries both types are often present. This is reflected in the guidelines: in Denmark the emphasis in the guidelines is on cycle tracks (cycle lanes are present but no separate guidelines are available for lanes); the Dutch and German guidelines contain recommendations for both types of facility, and the emphasis in the guidelines for the United Kingdom is on cycle lanes and 'shared facilities'.

Finally, the impression is that deviations from the guidelines concerning bicycle facilities at intersections seem to occur frequently. For instance, in Germany a lot of cycle tracks are under the standards and they cause many problems, with pedestrians as well (Steinbrecher 1994; personal communication).

Recommendations

For those EC-countries that at present do not have specific guidelines for bicycle facilities at intersections the recommendations as summarized in this report, and in particular *the above mentioned 'common solutions' can be a good starting point for drawing up such guidelines.*

Bicycle facilities at intersections that are supported by evidence indicating their safety should be the ones to serve as standards. However, as already stated, it appears that no strong safety evidence is to be found in the guidelines themselves. The described common solutions could form the first step towards 'standards', but *systematic 'screening' of the guidelines in connection with existing research findings* is considered a worthwhile exercise in order to provide standards with grounded safety implications. Then it will also become clear where there is a lack of evidence and need for further research. The impression so far is that research on the safety effects of specific bicycle facilities at intersections is scarce. Therefore, *comparisons between various bicycle facilities by means of accident and behavioural studies*, both within and between countries, are recommended.

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