Design of traffic areas

For cyclists the design of traffic areas is a question of ease of passage, perceived risk and safety. In order to choose the right solution it is important to identify the problems that one wishes to solve or prevent, and to consider whether the solution will create other problems.

A good design is both functional and easy to understand. For safety reasons it is important keep the number of errors in the traffic system as low as possible. And when accidents do happen nevertheless, it is important to minimise the possible consequence of these errors so that serious injuries can be avoided. Natural behaviour by road users should be safe behaviour.

PHOTO: Lars Bahl

PHOTO: Road Directorate

Contents

Adapted design **64**
Mixed traffic **64**
Cycle lanes **68**
Paved shouldes **71**
One-way cycle tracks **72**
Two-way cycle paths **77**
Priority junctions **82**
Signalised junctions **85**
Roundabouts **90**
Pedestrian areas and squares **93**
Bridges, tunnels, hills and stairs **94**
One-way streets **97**
Traffic control measures **98**

Adapted design

A basic principle is that the design of a traffic area should be self-explanatory. Everybody should have a clear understanding of their "natural" place in the traffic at all times. Road design should be determined by the speed and number of road users and by the composition of traffic. The pavement, signs and marking in a pedestrian street are not the same as on a highway. This is a matter of 6 kph architecture versus 80 kph architecture. Together with the multiplicity of functions that roads and paths fulfil these principles constitute the complex of demands that the design of traffic areas must meet.

PHOTO: Road Directorate

Closed railway lines now serve as paths for cyclists and pedestrians.

Paths in a separate layout

These paths are established exclusively to satisfy the needs of pedestrians and cyclists. The latter are not fond of hills or of stopping. Paths in a separate layout with too many hills and stops are a waste of funds – give priority to paths that cross roads and let the motorists give way.

Shopping streets

In shopping streets the most import thing is space for pedestrians. If people cannot move around on foot, without risk and obstructions, there will be no trade. If pedestrians are to be able to cross shopping streets without difficulty, the maximum desired speed for motor vehicles is 30 kph, and then there is rarely need to establish cycle tracks. If there are many motor vehicles passing through, the street is in reality divided into two shopping areas, and then a good idea is guard rails between signalised junctions.

Residential streets

Here the main thing is to feel safe. Motor vehicle speeds must be kept low. A solid knowledge of speed-reducing measures and parking facilities for motor vehicles will make it possible to solve many of the problems on residential streets.

Main roads

The town's main roads – the great traffic arteries – constitute its traffic machine. Their most important function is to facilitate the flow of traffic. It is here that 70-80% of all road accidents in towns occur. It is here that we find the great conflicts between safety, the environment and ease of passage, and it is here that marginal factors make all the difference. In order to manage these conflicts effectively it is necessary to have an intimate knowledge of signing, marking, junction design etc.

Highways

At high speeds it is necessary to separate cyclists from motor traffic. For bicycle traffic the primary task is the establishment of cycle tracks and paved shoulders.

PHOTO: Road Directorate

Mixed traffic

Cyclists often feel unsafe in mixed traffic, especially with large volumes of motor traffic travelling at high speeds. The level of safety depends on such factors as speed levels, parking conditions and the width of the road. Bicycles and motor vehicles should therefore only be mixed where there is little motor traffic and speeds are suitably low.

What is this? Cycle track or parking lane?

PHOTO: Road Directorate

Here the speed is naturally low.

PHOTO: Road Directorate

It is a good idea to reduce speed on this road by eg humps.

6 cyclists out of 10 experience problems in mixed traffic, while on roads with cycle tracks only 1 cyclist in 3 experiences problems. The behaviour of other road users, parked cars and junctions are frequently giving problems for cyclists in mixed traffic, while junctions and side roads give cyclists problems on cycle tracks [30].

Almost half of all cyclist deaths and injuries in Denmark occur in mixed traffic [135].

Cross section

The width of the carriageway plays a relatively small role in cyclists' level of service in urban areas [68]. The width of urban roads has only slight or no impact on the safety of cyclists, while their risk declines with increasing carriageway widths on highways [39, 81].

With a carriageway width of under 6.5 m motor traffic should not exceed 30-40 kph. Higher speeds require wider carriageways. If motor traffic is travelling at speeds higher than 40 kph, one should consider reducing the speed level or separating cyclists from the motor traffic.

On roads where motor vehicles drive at 30-50 kph and often overtake cyclists at the same time as opposing traffic passes in the other direction, the choice between separating cyclists from motor traffic and mixing cyclists and motor traffic on a broad carriageway should depend on, among other things, the volume of traffic, parking conditions and the amount of space available.

Parking

Parked motor vehicles are often perceived as a problem by cyclists in mixed traffic, and the accident risk for cyclists in mixed traffic does in fact rise with the presence of parking bays and bus stops [81, 114].

Parking manoeuvres and open car doors can injure cyclists. Scattered parking along a road can make cyclists less visible for other road users. Either parking should take place in parking lanes and bays or motor traffic speeds should be reduced to around 30 kph.

With angle or perpendicular parking motor traffic speeds should only be 10-20 kph.

Prohibiting parking leads to a 20-25% reduction in accidents even though it can also result in higher speeds [29].

Where there is parking only on one side of the road, the accident risk is even higher because this result in dangerous parking manoeuvres and changing visibility conditions.

PHOTO: Danish Cyclists' Federation

With high traffic volumes and many parked cars it is often a good idea to separate motor vehicles and bicycles.

PHOTO: Road Directorate

Footway crossovers shelter parking.

PHOTO: Road Directorate

A bus bay.

Bus stops

With bus bays head-on collisions between cyclists and motor traffic are avoided, and cyclists do not need to look back to check on buses and cars. In fact, cyclists rarely check on what is behind them.

In streets with a lot of parking a stopping and parking prohibition at bus stops can be supplemented with build-outs. In mixed traffic footway widening at bus stops will often be inconvenient for cyclists.

Traffic calming measures

Physical traffic calming measures are often necessary in mixed traffic in order to improve road safety and reduce perceived risk for cyclists.

In connection with chicanes and narrowings it is important to have an independent area for bicycle traffic – a cycle gap, track or lane. Cyclists feel safer when passing chicanes and narrowings with a cycle gap than without [24, 113]. It is important to keep 10-15 m before and after the cycle gap free of parking, eg by the use of build-outs or 30-40 m long cycle lanes.

Parking lane prevent slalom cycling.

PHOTO: Road Directorate

Play on bikes and cycling in the wrong side of the street is common on streets with few cars and low speeds.

PHOTO: Lars Bahl

PHOTO: Road Directorate

A good cycle gap is 1.3-1.4 m wide. If the cycle gap is too narrow cyclists will use the carriageway, and if it is too wide some cars will use the cycle gap.

Area-wide traffic calming and speed reduction will lead to an increase in pedestrian and bicycle traffic, most markedly for children and the elderly [101].

An English study of accidents in 72 traffic calmed areas reported a fall in the number of accidents of more than 60%. The decrease was greatest for motor vehicles and pedestrians and lowest for cyclists. The average speed of motor vehicles fell from 40 kph prior to traffic calming to 26 kph after [102]. Speed reducing measures do not have the same beneficial effects for cyclists as for other road users, among other things because the majority of bicycle accidents occur at junctions.

PHOTO: Road Directorate

Rumble devices can lower speed.

PHOTO: Road Directorate

Mini-roundabouts are speed reducing.

PHOTO: Road Directorate

Humps are very efficient as speed reducers. The hump can be constructed from kerb to kerb without cycle gaps, which is best for cyclists and the cheapest construction.

PHOTO: Road Directorate

To prevent side by side collisions cycle tracks or lanes can be established at central islands.

PHOTO: Road Directorate

Cycle gap, manhole cover, dirt and parking - a bad combination.

PHOTO: Road Directorate

Mini-roundabout on road section with cycle lane.

At junctions cyclist safety on quiet urban roads with mixed traffic is relatively good compared to cyclist safety on urban roads with cycle tracks or lanes. Cyclist safety on highways with cycle tracks is satisfactory – also at junctions. Mixed traffic necessitates greater interaction among road users.

PHOTO: Lars Bahl

Cycle lanes

Cycle lanes are mainly used in urban areas. Cycle lanes can be a good alternative to cycle tracks, and where lack of space or funds makes it impossible to establish cycle tracks. Broad cycle lanes give a large reduction in accidents on road links, but can give rise to safety problems at junctions. Three studies have each shown a 10% rise in the number of bicycle accidents in connection with the establishment of cycle lanes in urban areas. The total increase in accidents is a result of a large drop in accidents on road links and more accidents at junctions [16, 83, 94].

PHOTO: Lars Bahl

Bicycle symbol.

Studies indicate that accidents on road links in connection with parked motor vehicles do not disappear with the establishment of cycle lanes. Rear-end collisions, where motor vehicles hit cyclists from behind, still occur because of too narrow lanes [1, 83].

Road users turning left are a big problem on roads with cycle lanes. The severe accidents at junctions occur with cyclists turning left.

At motor vehicle speeds of 40-50 kph cycle lanes can be a good permanent solution, if there are few junctions and a modest need for parking cars.

Mini-roundabouts, marked cycle crossings and reducing motor vehicle speed are measures that may be able to eliminate some junction accidents on roads with cycle lanes.

Danish traffic counts show that establishing cycle lanes on a single road brings about a minimal increase (0-5%) in the number of cyclists [83]. If, on the other hand, a whole network of cycle lanes is established in an urban area without cycle tracks and paths, the number of cyclists will increase. In comparison with cycling in mixed traffic cyclists feel safer on cycle lanes and experience them as a real improvement in the level of service [68].

PHOTO: Road Directorate

A daily battle about space.

Establishing cycle lanes

In Denmark, a cycle lane is marked on the carriageway with a 0.3 m broad, unbroken edge line and bicycle symbols at intervals of ca. 100 m and after each interruption of the edge line (after junctions). Bicycle symbols can be replaced with a cycle track sign at junctions. The cycle lane is established on both sides of the road for one-way bicycle traffic. Motor vehicles are not permitted to park on the cycle lane, but unless there is a parking prohibition, parking is permitted between the motor traffic and the cycle lane.

Ever since the 1930s cycle lanes and the like have in certain situations been viewed as a temporary solution that should be replaced with cycle tracks in due course. One possibility is to stripe cycle lanes if cycle tracks are only to be established a number of years later. This signals that the area is reserved for cyclists in the future, while problematic junctions and road links can be identified prior to the planning of cycle tracks.

Cross section

Cycle lanes should be at least 1.5 m wide including the 0.3 m edge line. Where the lane is narrower than 1.5 m, overtaking cyclists often use the carriageway [17]. Reasonable overtaking conditions require a width of 1.7 m. The edge line itself must be continuous, but may, for instance, be profiled. Thermoplastic is a good material for marking with regard to visibility, durability, friction and cost [20].

Cycle lanes can be paved in different colours, eg red or brown, from the rest of the road to emphasise the cohesion of the cycle routes and the purpose for which they are intended. The coloured pavement can be continued through junctions marked as a cycle crossing with a broad broken line and bicycle symbols.

Coloured pavements give fewer disturbances for bicycle traffic from motor vehicles, and cyclists are positive towards colouring [37].

Coloured pavements are important on cycle lanes broader than 1.8 m, as these may be mistaken for parking or traffic lanes. There is no documentation of the safety impact of coloured cycle lanes.

A number of studies have pointed out that narrow cycle lanes are less safe on road sections than mixed traffic [45]. If the width of the cycle

Good different colour - but an unsafe dividing verge.

PHOTO: Road Directorate

Parking occur despite it is prohibited.

PHOTO: Road Directorate

PHOTO: Road Directorate

Marked parking spaces reduce the number of parked vehicles on the cycle lane.

PHOTO: Road Directorate

Too narrow parking bay - a car door is 0.9 m wide.

lane is increased, there is a greater distance between cyclists and motor vehicles, and there is a fall in number of cyclists who make brief excursions onto on the traffic lane.

Parking

Parking should be prohibited on roads with cycle lanes if there is much coming and going of parked motor vehicles as is the case for roads with shops or multi-storey buildings. Parking spaces must always be designed so that the area cannot be used for anything else than parking, eg an extra traffic lane at peak hours.

Where parking is permitted between the cycle lane and the traffic lane, a 2 m broad cycle lane will allow cyclists to overtake safely and improve their chances of avoiding open car doors and pedestrians. Where possible, a 1 m broad island or ghost island can be established between the cycle lane and the parking lane. Sheltered parking outside the cycle lane is a good alternative. If the sheltered parking areas are close together, the cycle lane can be regarded as a cycle track. If this form of cycle track is unusual in an urban area, signing or bicycle symbols can be used to make it clear what this part of the road is to be used for.

Parking between the cycle lane and the footway calls for a broad parking bay of 2.5 m so that motorists do not open their doors onto the cycle lane. On the other hand, the cycle lane does not have to be wider than normal, but the edge line must be broken.

Only parallel parking can be accepted on roads with cycle lanes. Angle and perpendicular parking increases the accident risk so markedly that these types of parking can only be accepted in car parks and on minor local roads, where cycle lanes are unnecessary.

Bus stops

At bus stops, depending on how much space there is, one can establish a bus bay, a short cycle track or

This design is unsafe!

PHOTO: Road Directorate

A broken edge line next to the bus bay is missing.

PHOTO: Road Directorate

PHOTO: Road Directorate

PHOTO: Road Directorate

PHOTO: Road Directorate

PHOTO: Road Directorate

Different edge lines.

a bus-boarder between the cycle lane and the traffic lane. This means that bus passengers do not have to struggle with high steps when boarding and alighting. Along the bus bay the cycle lane should be marked with two broad broken edge lines and extra bicycle symbols.

Paved shoulders

Paved shoulders can be used to advantage in rural districts and through villages. Besides giving cyclists the possibility of cycling on them, paved shoulders also give pedestrians a safer possibility of walking on a pavement. In addition, paved shoulders, if sufficiently broad, lessen problems with degradation of a road's edge [92]. The broader the paved shoulder, the more acceptance it receives from Danish cyclists [114]. Parking is permitted on paved shoulders.

The majority of bicycle accidents on roads with paved shoulders is rear-end collisions, where motor vehicles hit cyclists from behind [135].

Paved shoulders are established by moving the edge line or by widening the carriageway. It is not advisable to widen the carriageway to get room for a paved shoulder. This is because widening the carriageway costs the same as cycle tracks, but does not improve the level of service and road safety nearly as much for cyclists [81].

The marking of edge lines can result in increased motor traffic speeds [20, 91]. A good proportion of the accidents on roads with paved shoulders occur with cyclists turning left. In general, the establishment of paved shoulders and cycle lanes will not reduce this kind of accident [71].

Bus bays and paved shoulders go well together.

PHOTO: Road Directorate

Cross section

The recommended width of paved shoulders in urban districts is 1.5 m

PHOTO: Road Directorate

Broken edge line and hump.

including 0.3 m unbroken edge line. In rural areas the recommended width is 1.2 m with edge line, but it should not be less than 0.9 m. The paved shoulder must be a minimum of 0.9 m with edge line, if 0.3 m edge lines are to be used. Otherwise the edge line may only be 0.1 m broad in Denmark. The edge line must be unbroken.

The width of paved shoulders is decisive for their safety impact in rural areas. Overtaking, cycling side by side and cycle trailers do not function on narrow paved shoulders. Motorists are surprised by cyclists' temporarily use of the traffic lane. On roads with cycle tourists and roads with more than 100 cyclists per day the paved shoulder should be 1.5 m wide, but a cycle track or cycle lane is to be preferred.

A Danish before-and-after study shows that the number of accidents on highways falls in step with increased width of paved shoulder. The fall is greatest for vulnerable road users [92].

Parking

Especially in urban areas stopping and parking prohibitions should be considered, as broad paved shoulders can be used for undesired parking. In urban areas the possibility should always be considered of turning paved shoulders into cycle lanes – ie marking bicycle symbols, which means that parking is forbidden.

Road administrations receive complaints from motorists who do not know the parking rules for roads with paved shoulders. As an experiment broken edge lines have been used on paved shoulders in villages in Northern Jutland to make it clear that motor vehicles are permitted to park on the paved shoulders [91]. Paved shoulders are easier to implement than cycle tracks and cycle lanes, as they do not involve parking restrictions. In villages extended along a through road it is rarely possible to park elsewhere than on the through road, which means that paved shoulders together with traffic calming may be a good solution.

Cycle tracks

One-way cycle tracks are established along roads with large volumes of motor traffic and/or high speeds. The choice of track type and width should not depend solely

A cycle track with dividing verge is a fine solution on highways.

Separated cycle-footway is useable at low cyclist and pedestrian volumes.

PHOTO: Road Directorate

4 types of one-way cycle tracks

Extruded kerbs can function, where very few pedestrians cross the road.

The Danish cycle track gives a good separation between road users.

PHOTO: Road Directorate

A 2.6 m wide cycle track is necessary, if this manoeuvre must be easy and safe – however, it is illegal in Denmark.

on criteria like road safety and costs, but also on ease of passage, perceived risk, comfort and what can be experienced en route. The establishment of cycle tracks reduces the number of accidents involving cyclists and motorists on road links. Almost half of all bicycle accidents in Denmark occur on roads with cycle tracks. With desired speeds above 50 kph cycle tracks contributes to lessening the severity of bicycle accidents.

There are 4 main types of cycle track along roads with differences in costs, space requirements,

On roads with cycle tracks one accident in four occurs on road links. On road links, one accident in four is single accidents and half of the accidents are between pedestrians, cyclists and moped riders [135].

drainage and experienced level of service.

On highways the safety impact is greater for broad than for narrow cycle tracks [81]. Accident figures for cyclists are halved in connection with the construction of cycle tracks along highways, while the effect in urban districts depends on, among other things, the volume of motor traffic [58, 81]. The more motor traffic, the greater the impact [3].

The construction of cycle tracks appears to have a modest traffic calming effect on both cyclists and motorists. Depending on the breadth of the traffic lanes and possibly on a reduction in the number of traffic lanes a fall of about 1-5 kph in motor traffic speeds can be expected. Cyclists ride 1-2 kph slower on cycle tracks than in mixed traffic [86].

Cyclists prefer cycle tracks or separate paths with good lighting and a smooth pavement. Sometimes cyclists have negative experiences of cycle tracks, and this is primarily due to uneven pavements, manhole covers, gratings, junctions with obstructed visibility, narrow track profiles or poorly designed bus stops. A foreign study has shown that in comparison with cycle lanes cycle tracks give cyclists a significantly higher degree of experienced level of service [89]. Counts before and after the construction of 25 km of cycle track along 10 Danish main highways showed an increase of 37% in the number of cyclists on these roads [115].

Cross section

Both in urban and rural areas the recommended width for cycle tracks separated by a kerb, a verge or extruded kerb from the carriageway is 2.2 m. The recommended minimum is 1.7 m. For cycle tracks that are part of a separated cycle-footway the widths are 1.7 m and 1.5 m respectively.

Studies show that the accident risk for cyclists falls with increased width of cycle track and increased width of separating verge on highways [81].

A cycle track width of 2.2 m will ensure that overtaking can take place safely. As cyclist speeds vary considerably, there is much overtaking among cyclists.

Dividing verge

Dividing verges between the cycle track and the carriageway are a good solution on roads with high

Trees can be placed between footway and cycle track.

PHOTO: Road Directorate

The dividing verge should end 20-40 metres before the junction in order to increase cyclists' visibility.

PHOTO: Road Directorate

speeds and few junctions per km of road. Verges are especially used on highways, so that the laying of kerbs and drainage can be avoided. For reasons of safety, verges should be avoided on urban roads with closely spaced junctions.

Dividing verges with grass up to the carriageway are favourably assessed by cyclists, as they give lower perceived risk and a greater sense of comfort [114]. To avoid parking on the verge and to improve drainage conditions a kerb between the verge and the carriageway is recommended for urban roads.

The width of the verge should be determined on the basis of an overall assessment of wishes regarding vegetation, requirements concerning visibility and distance from solid objects and space conditions. On highways 1.5 m verges are normal, while their widths vary more in towns. On highways fixed objects, eg trees, must not be placed on verges as they impair motorist road safety.

Verges with trees between the cycle track and the carriageway should be at least 2 m broad in towns. Trees between the footway and the cycle track can be planted in a 1-1.5 m wide verge. A grass verge should be at least 0.6 m wide.

PHOTO: Road Directorate

PHOTO: Road Directorate

Despite change in pavement too narrow cross sections is a problem.

As a rule, safety fences should be placed on the shoulder, as a placing between the carriageway and the cycle track renders mowing, snow-clearing etc, more difficult and more expensive. Safety fences on verges may make emergency stops unsafe.

Separated cycle-footway

A separated cycle-footway without kerb between pedestrians and cyclists can be established where there is sparse bicycle and pedestrian traffic and where there is not much space. With the cycle track and the footway at the same level and distinguished only by marking or differences in pavement, there is a greater risk of accidents between cyclists and pedestrians. Pedestrians will tend to stray onto the cycle track more or less unawares unless marking and pavement clearly indicate who should be where. The narrower the cycle track, the more cyclists will tend to use the footway.

Extruded kerbs

The choice of extruded kerbs instead of conventional kerbs is primarily due to economic considerations. The basic idea of extruded kerbs is to avoid expenditure on drainage and laying kerbs while obtaining the advantages of cycle tracks. In general, cyclists feel slightly safer on extruded kerb tracks than in mixed traffic. Road users may react negatively towards extruded kerbs if the extruded kerb is not sufficiently conspicuous, and pedestrians tend to stumble over them. Extruded kerbs can be obtained in various forms and materials, eg rubber, plastic, concrete, asphalt and kerbstones.

At junctions the extruded kerb should be interrupted.

The extruded kerb can be made visible by starting it as an island at a junction and by marking edge lines and making differences of pavement. At private drives and driveways extruded kerbs made of concrete, asphalt and kerbstones should be provided with asphalt slopes. Other types of extruded kerb should be interrupted. Deformation problems and the like can occur because of wheel pressure from trucks and buses. Road drainage should take place through 30 cm wide gaps in the extruded kerb. The gaps should be placed 1 m upstream from the drain or at regular intervals on roads without sewers. It has not been documented whether extruded kerbs increase or reduce the number of cyclists [66].

Extruded kerbs should not be constructed, where many pedestrians cross the road. As ordinary kerbs

PHOTO: Road Directorate

The kerbs separate road users.

the height of extruded kerbs should be about 10 cm.

Danish cycle tracks

On free sections of road, kerb heights along the carriageway should measure between 7 and 12 cm and between 5 and 9 cm between the cycle track and footway. These heights give a number of advantages. Most motorists refrain from parking on the cycle track. Vehicles exit from and entry to properties take place at low speeds. Drainage functions well. Cyclists rarely cycle on the footway, and pedestrians will register when they leave the footway. The heights represent a balance between positive and negative factors, such as pedestrian and cyclist accidents from falling and also mobility problems for the disabled.

PHOTO: Road Directorate

Island between parking bay and cycle track.

PHOTO: Road Directorate

The island between the cycle track and the carriageway makes it safer for pedestrians to cross the road.

PHOTO: Road Directorate

Well-constructed drainage is important - here the depression around the gully is too big.

Drainage takes place through gullies on the carriageway and the cycle track. If gullies on the cycle track are to be avoided, the whole road foundation must be lowered. Gully gratings on cycle tracks do not make the cycle track significantly narrower as cyclists ride at a safe distance from the kerb. On the other hand, depressions around gratings are a problem.

Car parking

On sections of road where there is a strong need for stopping and parking it is possible to establish a dividing island with a recommended width of 1.0 m between the carriageway/parking lane and the cycle track. It is not necessary to have a kerb between the island and the cycle track. The island should be paved differently from the cycle track.

The construction of cycle tracks leads to a big reduction in the number of accidents involving cyclists and parked vehicles. In Denmark stopping and parking on cycle tracks is illegal.

On roads with motor vehicles parked outside the cycle track,

PHOTO: Road Directorate

Boarding passengers at bus stops without bus-boarder may stand on the cycle track long before the bus arrives.

PHOTO: Road Directorate

Zebra crossings in line of the bus doors improve safety. The profiled marking gives a safer distance between cyclists and bus passengers.

PHOTO: Road Directorate

At bus-boarders pedestrians must give way for cyclists in Denmark.

PHOTO: Road Directorate

The cycle track is behind the waiting area etc.

islands between the cycle track and carriageway can improve pedestrian safety and help to prevent pedestrians from waiting on the cycle track. Another possibility is to remove some of the car parking and establish a pedestrian refuge.

Bus stops

The construction of cycle tracks can increase the number of accidents at bus stops unless special safety measures are introduced. Accidents with alighting passengers occur mainly at places where there is only a narrow or no bus-boarder, while accidents with passengers entering a bus occur at bus stops with a broad bus-boarder. Almost all accidents at bus stops where there is no bus-boarder involve alighting passengers and cyclists.

Studies of bus passengers and cyclists at bus stops without a bus-boarder have shown that the marking of zebra crossings reduces cyclist speeds in connection with stopping buses considerably, and that the number of serious conflicts between cyclists and bus passengers is reduced [45]. The establishment of give-way markings, rumble devices and painted patterns at bus stops does not have the same positive impact as zebra crossings [31, 32].

At bus stops on roads where there are cycle tracks with extruded kerbs, it is a good idea to establish a section of ordinary cycle track with kerb height differences in respect of both the carriageway and footway.

On roads with cycle tracks bus stops should be placed at least 20 m before the junction, otherwise stopping buses will reduce cyclist safety and their visibility for other road users. The bus stop should never be placed immediately before the stop line at signalised junctions, as stopping cyclists will then block the way for boarding and alighting bus passengers.

PHOTO: Road Directorate

The cross kerb creates discomfort.

PHOTO: Road Directorate

Discomfort, danger and unlit.

PHOTO: Road Directorate

A smooth transition and a logical continuation of the track.

A bus-boarder should be at least 1.5 m wide and have a different pavement from that of the cycle track. At bus stops where there are many boarding and alighting passengers a width of 2.5 m can ensure that the bus-boarder is not overfilled, and that passengers with prams can board and alight in safety.

Boarding and alighting from buses are experienced as the next most dangerous situation by elderly pedestrians along Frederikssundsvej in Copenhagen. About half of the elderly experience problems with cyclists at bus stops very frequently [65].

Start and end designs

The design of the start and end of cycle tracks is an important part of the detailed design. The start and end of a cycle track should be formed as a smooth transition between road and track, as a direct continuation of the pavement of the track and without edges. It is an advantage for cyclists if existing cross kerbs are removed.

The conclusion of a cycle track in mixed traffic can be realised as a 15-20 long wedge-formed widening of the carriageway, with an edge line marked from the end of the cycle track to 15-20 m after the widening of the carriageway. The carriageway should not be narrowed if the cycle track is continued as a paved shoulder or cycle lane, and cyclists should be able to continue on their way without a lateral change of direction. If the cycle track ends abruptly, the attention of motorists can be drawn to this fact through signing and the establishment of an approx. 1 m wide build-out, which prevent rear-end collisions.

Cyclists have to walk across the zebra crossing to a cycle path close to a side road or use an entry to the cycle path to the right about 70 m before the zebra crossing. But cyclists behave differently!

PHOTO: Road Directorate

PHOTO: Road Directorate

Cycle path along a road.

Cycle paths

Two-way cycle paths are established through recreational areas, as short cuts between towns, as path systems in residential areas or along major roads with few junctions. Cycle paths often function as shared-use paths for pedestrians and cyclists. Cycle paths have an independent cross section, entirely separate from any nearby roads.

Cycle paths can be divided into two main types:
1) Cycle paths along roads, and
2) Cycle paths in a separate system through green areas, residential areas etc.

Cycle paths along roads

Cycle paths along roads should only be established after a safety assessment of this solution in relation to other solutions for vulnerable road users, and only as an exception. Two-way cycle paths mean a broader area for the individual cyclist, but are not as safe as one-way cycle tracks at junctions, private drives and driveways. Cycle paths are cheaper to construct than cycle tracks.

Cycle paths should not be established along roads where there are many side roads, driveways etc, across the path, eg in towns. Safety problems arise where a cycle path crosses side roads because it is often difficult for motorists to realise that cyclists can come from the “wrong” direction. The solution here is one-way cycle tracks on both sides of the road.

Cycle paths can be established where there is a lot of motor traffic and there is plenty of space, eg along motorways or busy highways. From a road safety perspective it is usually best to place the cycle path on the side of the road that has the fewest side roads, driveways etc.

Paths in a separate layout

Paths through recreational or residential areas can offer short, more attractive, safer routes with less perceived risk, where it is the cyclist’s needs that are in focus. In residential areas the paths offer good conditions for bicycle traffic, especially for children and the elderly.

A path in a separate layout can be used by younger children without being accompanied by an adult as long as the path does not cross larger roads on the same level. At the same time the paths can be used to offer cyclists short cuts between important destinations such as schools, shopping etc. Paths in a separate layout can also be estab-

PHOTO: Road Directorate

Path in a separate layout.

PHOTO: Jens Erik Larsen

Every 10th tourist in Denmark cycles.

PHOTO: Road Directorate

This curve does not conceal cyclists!

lished with a view to cycle tourism and recreational purposes.

In some cases a path in a separate layout can mean detours for cyclists. Cyclists will often have to give way where the path crosses roads, which means delays for cyclists. The path may also have shorter curve radii in both horizontal and vertical curves than roads.

Cross section

Paths should be designed to allow two cyclists with trailers to pass one another. If there is also to be room for pedestrians, further width is needed. A two-way shared-use path should therefore be at least 3 m wide, and a two-way cycle path should be at least 2.5 m wide with a separate pedestrian area alongside. The breadth of the path is crucial for cyclist comfort and ease of travel. The recommended breadths permit two people to cycle side by side and thus talk to one another on their cycle trip.

PHOTO: Road Directorate

Long hill, but no visibility obstructions along the track and in tunnel.

In urban areas the verge between the carriageway and the cycle path should be at least 1.0 m wide. Along highways the minimum width of the verge is 1.5 m [76]. For main roads a dividing verge of 3 m in width is recommended. If these verges are narrower, or if the cycle path is closer than 15 m to a motorway or expressway, safety fences should be erected between path and road [121].

Horizontal and vertical radii

To prevent dangerous situations between road users moving in opposite directions on paths with two-way traffic, curves must be designed so that there is double stopping sight. This also applies to curves in tunnels, at junctions with other paths etc. If there is mopeds on the path, the curve radii must be designed so that moped riders also have double stopping sight.

If it is not possible to obtain double stopping sight, opposing traffic must be separated by a central island, verge or the like. A cheap solution is to mark a central ghost island on the path.

It should be possible for both bicycles and mopeds to pass through any curve at a speed of 30 kph. Where a horizontal curve coincides with a vertical curve, it may be necessary to design for higher speeds for both bicycles and mopeds so that cyclists do not lose control in the curve. On horizontal curves with radii of less than 50 m the path must have cross fall towards the centre of the curve.

As a minimum requirement there should be double stopping sight on vertical curves on cycle paths. If there is mopeds on the path, it should be designed for mopeds.

Gradients

As we all know, the energy needed to pedal the bicycle forward has to be produced by the cyclists themselves. For this reason the number of cyclists using a path will depend on the steepness of the gradients on the path. Furthermore, cyclist safety will depend on the steepness of the downhill sections of the path. It is therefore necessary to operate with maximum gradients on paths.

Gradient and energy consumption sets a limit on the length of uphill sections. For paths in a separate layout it is economically feasible to adapt vertical alignments, which are not a problem for cyclists. The steepest sections can with advantage be at the beginning of hills.

Gradient	Max. length
50 ‰	50 m
45 ‰	100 m
40 ‰	200 m
35 ‰	300 m
30 ‰	500 m

Cyclist safety declines if steep descents are combined with sharp horizontal curves. For a gradient of 50% the design speed should be 40 kph and for a gradient of 30% it should be 36 kph. It is therefore

PHOTO: Road Directorate

Path users have to give way.

PHOTO: Road Directorate

Cyclists know all short cuts.

necessary to devote special consideration to the design of paths in connection with tunnels and bridges.

Path junctions

Path junctions have hitherto been a neglected problem in Denmark. It is important that there are good visibility conditions at path junctions so that cyclists and moped riders can obtain an overview of crossing traffic. It is also important to establish clear give-way conditions where there are many cyclists and it is not possible to obtain adequate visibility conditions.

If speeds are too high at path junctions – either because the junction is situated at the bottom of the hill or because cyclists ignore priority rules – traffic calming for cyclists can be a solution. This may be achieved through speed reducing exit constructions in the form of humps or undropped kerbs. The path with the obligation to give way can be formed with a rise up towards the main path. As paths are established to improve conditions for bicycle traffic, traffic calming should be used only where there is a real problem.

Junctions with roads

At junctions of paths and roads and at the ends of paths conflicts arise between cyclists and motorists. It is particularly the party that has the obligation to give way that should recognise the problem. It is important to have uniformly good visibility conditions on both sides of the junction.

When it is motorists who have the obligation to give way, traffic calming or signal-control are required to make motorists aware and get them to accept that they do not have priority. If traffic calming or signals are not acceptable, the obligation to give way must be imposed on the cyclists for the sake of their own safety.

There are many solutions that can make cyclists aware of and accept the obligation to give way where paths cross roads. When cyclists have to yield priority, there should be at least 30-40 m between the path-road junction and other junc-

The cycle path crosses the road on a flat-topped road hump, where motorists must give way for cyclists.

PHOTO: Road Directorate

PHOTO: Road Directorate

PHOTO: Road Directorate

The signal is activated by detectors below the path surface, so cyclists rarely have to stop.

PHOTO: Road Directorate

Nice rock, but hard to see in the evening.

tions. Stop signs or give-way markings can be used with other solutions. As at path junctions, humps, undropped kerbs and upward inclines can be established approaching the road – or one can establish speed reducing exit constructions as at side roads, where the footway or verge is formed as a raised surface with the help of flags, sett paving etc.

Finally, access barriers can be used to impose the obligation to give way on cyclists. This is an effective solution, but a lot of bother for path users. Sometimes access barriers are used to prevent motor vehicles from entering the path, but here bollards with reflectors are just as good. Access barriers should therefore be used only rarely. They should be sited about 5-7 m from the edge of the road so that the cyclist is brought to a position with a good overview of the situation. The nearest barrier should always be on the right, and barriers and bollards should be lighted and visible from the path at a distance of at least 30 m.

Many cycle paths along highways end on the outskirts of a town. The termination can be combined with traffic calming measures at a town gateway. A central island will make it possible for cyclists to cross the road in two stages. As it is important to avoid undesirable two-way bicycle traffic along one side of the road in a town, it should be relatively easy for cyclists to cross the road at the end of cycle paths. On very busy roads a tunnel may be the solution.

When paths in a separate layout end in a through-going road, motorists should not have to give way. The design is the same as when paths cross roads. It is a good idea to terminate paths in a separate layout at the end of cul-de-sacs – see how this can be done on page 98.

Many cyclists will try to avoid humps, undropped kerbs, access barriers etc. These attempts can most easily be prevented by laying kerbstones on both sides of the path with a height difference of 10-15 cm or by guard rails. Kerbs and guard rails should be placed so that cyclists have to cycle at least 20 m outside the path to avoid access barriers etc.

PHOTO: Road Directorate

The transition from two-way path to one-way cycle track is solved by access barriers, guard rails, central island and pinch point.

Other measures

Paths in a separate layout without lighting and paths in green areas are

PHOTO: Road Directorate

Accidents with cyclists in the "wrong" direction often occur at these junctions. Here path bridges/tunnels or a separate stage maybe with push-buttons for pedestrians and cyclists are good solutions.

very rarely used in the dark. Instead cyclists use the road system or desist from cycling. Bicycle lamps cannot illuminate the path. The lighting of paths in a separate layout should therefore light up the whole path, so that cyclists travelling at 25 kph can easily distinguish the path from its surroundings – otherwise the lighting is not worth much.

Safety

Paths in a separate layout give a high degree of safety and low perceived risk for cyclists, and severe accidents involving cyclists and motor vehicles do not occur on the path itself. The typical accidents on paths in a separate layout are single accidents and collisions with pedestrians, mopeds and other cyclists. A number of the accidents are due to slippery conditions, too high speeds, too sharp curves, poor visibility conditions and unclear priority situations at junctions. Remember that most accidents on paths in a separate layout – perhaps 95-99% - are not recorded by the police. In Denmark only 1 cyclist is killed annually at junctions between paths in a separate layout and roads [135].

Cycle paths along roads give rise to far greater safety problems. In connection with paths along main roads the problem is mainly that motor vehicles turning left from the main road and turning right from side roads do not see cyclists who are coming from the "wrong" direction. This causes accidents that are not infrequently very severe. Blue cycle crossings and signing rarely help much. Instead, flat-topped humps, roundabouts, separate signal stages and foot and cycle bridges/tunnels can be recommended – or give-way signs for cyclists.

Promotion of cycling

If paths in a separate layout are to be used to promote cycling, it is important to make it clear to oneself beforehand who one is constructing them for. In projects for the promotion of bicycle traffic the focus should be on the needs of cyclists, and therefore the obligation to give way must to a large extent be imposed on motorists. This means that cycle paths can function as short cuts for cyclists and be an enjoyable and worthwhile experience. In addition, cyclists must be ensured the possibility of cycling at high speeds – no sharp bends or too narrow passages, but a broad cross section and a good smooth pavement, please!

Priority junctions

There are two types of priority junction, namely junctions with priority for traffic approaching from the right and junctions with an unconditional obligation to give way, where the road user on a side road must stop and wait for traffic passing on the major road. Junctions with priority for traffic approaching from the right are rare in Denmark but are to be found in residential areas and are common in a few Danish towns. The unconditional obligation to give way is preferable to priority for traffic approaching from the right, which leads to more accidents. Some road users do not notice their obligation to give priority to traffic approaching from the right, while others are in doubt about the rules. One possibility is to change the obligation to give priority to traffic approaching from the right to an unconditional obligation to give way or put up stop signs in all directions. In the following only junctions with an unconditional obligation to give way will be discussed.

About one third of the injury accidents with cyclists in Denmark occur at priority junctions [135].

The most commonly occurring accidents at priority junctions are cross direction collisions and left-turn accidents. The serious accidents occur in particular when cyclists are crossing the major road.

Visibility and priority

It is important that priority conditions at a junction are clearly apparent. This can be achieved through signing, islands and conspicuous traffic calming measures such as speed reducing exit constructions.

Visibility conditions at a junction depend on bends, vegetation, lighting etc, and are of great importance for the safety of all road users. It is important that visibility conditions

PHOTO: Road Directorate

Parked cars conceal cyclists and obstruct visibility.

PHOTO: Road Directorate

Motorists may have difficulty leaving side roads.

should be uniform in both directions, as otherwise road users will focus so much on traffic from the direction where visibility is obstructed that they forget to look in the other direction.

Motor vehicles parked close to a junction can obstruct the view for road users. This can be a problem for traffic on the side road and on the major road. Cyclists on the major road should be visible to traffic on the side road and turning motorists on the major road at least 20 m before the junction. For downhill slopes on the major road the distance should be greater, eg 24 m for a 20% gradient and 30 m for a 50% gradient.

It must be possible to recognise the junction early enough. Remember that buildings, vegetation and parked motor vehicles can often be perceived visually as an unbroken line along the road, which makes it difficult to recognise that there is a junction. The visibility of the junction can be improved by parking prohibitions, breaks in the vegetation and marking.

The dividing verge between the cycle track and the carriageway should end in good time before the junction, partly to make cyclists more visible, and partly to ensure optimal visibility conditions from the side road.

It is difficult to make left turns at big priority junctions, eg where the major road has 4 lanes. With the view of the traffic presented to the

There are many types of speed reducing exit constructions.

PHOTO: Road Directorate

PHOTO: Road Directorate

PHOTO: Road Directorate

Harlequin pattern on continuous cycle track.

PHOTO: Road Directorate

Interrupted cycle track - the dividing verge should not be there.

motorist turning left it is relatively easy to overlook cyclists. Here markings can remind road users of the presence of cyclists, but there are also other solutions, eg roundabouts.

Continuous cycle track

At junctions with modest amounts of traffic the cycle track should be continued through the junction. Continuous cycle tracks have a traffic calming effect on vehicles entering and leaving the side road, since they have to pass across the cycle track and often also the footway. This speed reducing construction means that it is easier for traffic on the side road to register and understand the priority conditions and potential conflicts are avoided. Cyclists on the cycle track will presumably reduce the attention they give to the junction. A study of cyclist safety at minor priority junctions showed moreover that the establishment of speed reducing exit constructions in the form of continuous cycle tracks and/or footways led to a fall in the number of bicycle accidents of up to 50% [43].

To make the cycle track more visible through the junction the cycle track can be given a different pavement or it can be marked with bicycle symbols or a harlequin pattern. Behavioural studies suggest that the reciprocal awareness of motorists and cyclists increase by the use of harlequin patterns through junctions [84].

Interrupted cycle track

At junctions with more traffic on the side road the cycle track can be interrupted at the junction. An interrupted cycle track is more dynamic, so turning road users do so at higher speeds. On the other hand, cyclists come level with motor vehicles at junctions, which may increase mutual awareness.

An interrupted cycle track can be supplemented with a cycle crossing through the junction to draw attention to the cyclists' traffic area. Where there is a high risk for cyclists and moped riders, the cycle crossing can be established as a blue cycle crossing.

At priority junctions on highways the cycle track should nearly always be interrupted. The establishment of right-turn lanes should be avoided because the motor vehicles turning right obstruct visibility from the side road. If, however, there is a large amount of traffic turning right, one can establish a right-turn lane with a large ghost island or island between the right-turn lane and the carriageway, but without a dividing verge between right-turn lane and cycle track. The separation of motor vehicles and bicycles can be carried out with extruded kerbs, thereby avoiding drainage costs and ensuring that right turns are performed at a very low speed. Truncated cycle tracks at priority junctions with right-turn lanes cannot be recommended. One should instead insure that motorists turn slowly.

Cycle lane

Where a cycle lane along a major

PHOTO: Road Directorate

Short corner radii may lower turning motorist speeds at interrupted cycle tracks.

PHOTO: Road Directorate

Cycle crossing and continuous footway.

road is continued up to a junction, a cycle crossing should be established through the junction. An accident analysis of bicycle accidents at priority T-junctions in urban areas showed that accidents were less severe in cases where existing cycle lanes and tracks were continued through the junction as a cycle crossing [72]. In order to avoid side by side collisions between cyclists and motorists the cycle lane can be formed as a profiled strip on the last section before the junction. A continuous footway will increase cyclist safety.

Recessed cycle track

At priority junctions on busy major, possibly 4-lane, roads it may be a good idea to lead the cycle track 5-7 m away from the road and lead it over the side road on a raised surface. This makes it easier for road users entering and exiting the side road to assess potential conflicts with cyclists and at the same time gives them a good overview of the junction. The deviation should be 5-7 m to create room for an ordinary private car to wait without obstructing the rest of the traffic. The raised surface is necessary to make motorists respect their obligation to give way and to prevent them from stopping on the cycle track. Recessed cycle tracks should not be established when there are many trucks on the side road.

Mixed traffic

In mixed traffic it is a good idea to establish speed reducing exit constructions on side roads by continuing the footway without interruption through junctions [43]. It is also advisable to keep corner radii relatively short.

Cycle paths

Cycle paths and priority junctions are a bad combination and give rise to some safety problems that are difficult to solve if the path runs alongside the major road. If, instead, the path runs alongside the side road and crosses the major road, the problem is less pronounced.

Where it has been decided to establish cycle paths along major roads, it is important to make both cyclists and motorists aware of the conflict. Cycle paths should always be continued right up to the junction [34].

Where there is sufficient space, the cycle path can be recessed 5-7 m away from the major road and continued across the side road on a raised surface. The other possibility is to recess the path 30-40 m away from the major road and give the side road priority over the path. This means that cyclists will have to give way to traffic on the side road. This is not a cyclist-friendly solution, but may be necessary for safety reasons and out of consideration for the passage of motor vehicles. The 30-40 m recession is necessary, as at the junction cyclists cannot allow for traffic coming from all angles at one and the same time.

Traffic calming

It is also possible to raise the junction. It is, however, uncertain whether having raised junctions improves safety for cyclists. Raised junctions may mean unclear priority conditions. It is therefore important to indicate that there is an unconditional obligation to give way.

Speed reducing traffic islands can be a good initiative in rural areas to give road users on the side roads a better chance to catch sight of the junction.

PHOTO: Road Directorate

Recessed cycle track - the design speed is 20 kph for cyclists.

Signalised junctions

Signalised junctions are often established in expectation of a better traffic flow, road safety and lower perceived risk. The separation of crossing traffic flows in terms of time reduces the probability of cross direction collisions. Conversely, traffic signals will result in a concentration of conflicts between turning and straight-on traffic, which is normally not solved by signals [67].

About one out of six cyclist deaths and injuries occur at signalised junctions [135].

The most frequently occurring injury accidents involving cyclists at signalised junctions are accidents with motor vehicles turning left or right and cross direction collisions where the cyclist crosses against a red light [135].

The visibility of cyclists depends, eg on the geometrical and visual size of the junction. Parked motor vehicles and stopping buses near the junction may reduce the visibility of cyclists.

Right/left-turn stage for motorists

At junctions without a separate cyclist signal, the cyclists have to observe the signals for motor vehicles. Arrow signals apply to road users who wish to drive in the direction indicated by the arrow. However, cyclists are not allowed to use the left-turn arrow for motor vehicles, as according to the Danish Road Traffic Act they have to make left-turns in two stages. They first have to go to the opposite side of the junction before they make a left-turn when it can be done without inconvenience to other traffic, independently of whether the signal shows green or red [139].

Junctions with a left-turn stage for motorists reduce the number of accidents between left-turning motor vehicles and oncoming cyclists at large junctions with many traffic lanes.

PHOTO: Road Directorate

Pre-green can reduce the number of accidents at the start of the green stage.

PHOTO: Road Directorate

Separate right-turn stage - conflict-free - channelisation of cyclists.

Cyclist signals

At junctions with cycle tracks or cycle lanes to the stop line, a separate cyclist signal may be established. Cyclists may thus have their own signal stage. Cyclist signals can be used to give cyclists a pre-green signal some seconds before motor vehicles. This means that cyclists who start from red get a head start on motor vehicles, thus becoming more visible. The purpose is to reduce the number of accidents between motorists and cyclists.

Cyclist signals are also used to reduce green time for cyclists to facilitate the flow of turning motor traffic. At junctions with separate cyclist signals cyclists must always comply with these signals.

At junctions with two or more turning lanes in the same direction from

an entry road these turning lanes should have their own turning stage because it can be difficult to see the cyclists. Green time is thus reduced for cyclists riding straight on and turning left.

Detecting cyclists in vehicle-actuated operation

In vehicle-actuated operation, the duration of the green time is controlled by the traffic from the different directions. For motor vehicles loop detectors are milled into the road to report traffic to the signals. Bicycles can be detected through loop detectors or manually by push-buttons. In some places cyclists and pedestrians are detected by pushing the same button, while in other places they have separate posts.

The optimal way to detect cyclists is to establish a combination of loop detectors and a separate cyclist push-button placed on a low post at the stop line. When a cyclist has been detected, a control lamp lights up. If the control lamp does not light up as expected, the cyclist can activate the signal by pushing the button.

By inserting loop detectors in the cycle track/lane some way before and up by the stop line cyclists can be detected sufficiently early for the signal to change from red to green or to extend the green time so that the cyclist does not have to stop.

PHOTO: Road Directorate

Here left-turn loop detectors can be useful.

At some junctions, cyclists turning left can be detected only by placing loop detectors in front of the stop line. In order to prevent crossing cyclists from activating the signal unnecessarily, the loop detector must be activated for at least two seconds.

The advantage of detecting cyclists via loop detectors is shorter waiting time and that they do not have to push a button. Manual detection also has the disadvantage that not all cyclists are aware that they have to push a button, and that they become impatient and cross at red. The disadvantage of automatic detection of cyclists is that in order to be detected they have to stop or ride in a well-defined area. This area should therefore be marked or unavoidable.

Bypassing traffic signals

At signalised T-junctions with a cycle track up to and through the junction and with staggered stop lines, one can choose to let cyclists bypass the signals. This reduces the number of stops and gives greater ease of passage. The measure can be combined with a left-turn lane for cyclists. At the pedestrian cross-

Straight-on going cyclists bypass the signal, while left-turners have their own lane.

PHOTO: Danish Cyclists Federation

Right turning cyclists bypass the signal, but not the pedestrians.

PHOTO: Road Directorate

ing cyclists have to give way to crossing pedestrians. One possibility is to establish a pedestrian refuge between the cycle track and the carriageway to make the priority difference (signals versus pedestrian crossing) clear, and the island makes it possible to remove the pedestrian crossing from the cycle track.

At signalised junctions with enough room a right-turn lane can be established for cyclists before the signals. In this way cyclists turning right avoid having to stop at red lights.

Cycle track/lane to the stop line

At signalised junctions with a right-turn lane for cyclists and where cyclist speeds are low or normal, it is a good idea to continue the track/lane right up to the stop line and mark a cycle crossing through the junction. The cycle track/lane to the stop line has the advantage that it meets the cyclists' wish to have their own area and makes them feel safe.

At junctions with many trucks turning right a cycle track/lane to the stop line should be used with caution as truck drivers have difficulty in detecting cyclists on the right side of the truck [7]. Part of the safety problem with trucks can be solved by staggered stop lines.

Where the cycle lane is continued right up to the junction, side by side collisions between cyclists and motor vehicles can be avoided by separating the cycle lane from the traffic lane with a profiled stripe.

In order to make space for a right-turn lane and create a better interaction between motorists turning right and cyclists continuing straight-on, a broad cycle track/lane can be carried on in a narrow cycle lane the last 20-60 m up to the stop line. This solution may eliminate bicycle accidents with motor vehicles turning right, but it reduces the capacity for bicycle traffic if not combined with an advanced stop line.

Truncated cycle track/lane

At signalised junctions with cyclists travelling at high speeds it is important to truncate the cycle track/lane for safety reasons. The result of truncating the cycle track at least 20-30 m before the junction (the length depends on the number of motor vehicles turning right) is that cyclists and motorists are at the same level, are physically closer to each other, and both are responsible for obviating conflicts. In order to ensure sufficient space for motor vehicles as well as cyclists, the width of the right-turn lane should be 4 m wide or more. This is probably also a good solution where there are many mopeds. If truncation of a cycle track/lane is the only possibility of creating space for a right-turn lane, it is presumably also better from a road safety point of view to have a truncated cycle track rather than not having a right-turn lane.

At junctions with a truncated cycle track there should be no entries and exits on the 'truncated' section before the junction. Truncated cycle

PHOTO: Danish Cyclists Federation

Truncated cycle track continued in a narrow cycle lane.

A good profiled stripe. Staggered stop lines should have been established.

PHOTO: Road Directorate

Downhill – truncated cycle track.

PHOTO: Road Directorate

PHOTO: Road Directorate

Staggered stop lines do not reduce capacity.

PHOTO: Road Directorate

The blue carpet is rolled out.

tracks/lanes should not be used at junctions with many child cyclists as this solution creates a sense of perceived risk – and children cycle slowly.

Cycle lane between right-turn and straight-on traffic lanes

At large signalised junctions, a cycle lane can be introduced between the right-turn and the straight-on traffic lanes. The underlying idea is to replace the conflict between motor vehicles turning right and straight-on cyclists by having a less dangerous merging situation before the junction. At the same time straight-on riding cyclists are more visible for oncoming motorists turning left. This measure can be combined with a cycle crossing in the junction area. An accident study of this measure has not been able to document any safety impact [85].

Mixed traffic

In entry roads to a signalised junction with mixed traffic a short cycle lane can be established over the last 20-50 m before the junction. Cyclists are then given their own area up to the junction which results in lower perceived risk and greater ease of passage. Furthermore, this makes it possible to mark a cycle crossing through the junction.

Cycle crossing

Cycle crossings can be established at junctions where it is considered necessary to draw attention to conflicts between straight-on going cyclists and turning motorists. Apart from making the conflict area clearer, the cycle crossing separates cyclists and motorists from each other visually and makes cyclists feel safer.

In Denmark there are four different types of cycle crossing. One is blue, while the others are marked by white broken 0.3 m wide edge lines. Bicycle symbols are always marked.

An accident study of cycle crossings at signalised junctions has shown that the marking of cycle crossings has led to a 36% reduction in the number of bicycle accidents and as much as 57% in the number of severely injured cyclists. The study showed, furthermore, that especially accidents between motor vehicles turning left and straight-on cyclists were reduced by introducing cycle crossings at large junctions. Motorists seem to have transferred some of their awareness from pedestrians to cyclists as there was an increase in pedestrian accidents [55].

Mini cycle lane and blue cycle crossing at signalised junction.

PHOTO: Road Directorate

Staggered stop lines

At all signalised junctions it is recommended to recess the stop lines for motor vehicles by 5 m in all traffic lanes relative to the pedestrian crossing or the cyclists' stop line. Staggered stop lines make pedestrians and cyclists more visible in connection with a change of signal, and means that vulnerable road users enter the junction earlier so that many conflicts are avoided. An accident study showed a 35% reduction in the number of accidents between motor vehicles turning right and straight-on riding cyclists, and 50% in the number of injured cyclists in this type of accident [45].

In fatal accidents where a bicycle/moped is hit by another vehicle turning right, in 90% of cases the other party is a truck 7. Staggered stop lines make cyclists more visible to truck drivers.

Advanced stop lines

At signalised crossings advanced stop lines can be established with bicycle symbols in front of the stop lines for motor vehicles in the turning lanes. This makes it possible for cyclists who stop at a red light to keep in front of the motor vehicles. The advantage is that cyclists who stop at a red light become more visible for turning motor vehicles and that the cyclists enter the junction before the motor vehicles.
Advanced stop lines in front of left-turn lanes must only be marked on side roads at signalised T-junctions. At present advanced stop lines require special dispensation under the Road Standards and Guidelines in Denmark.

PHOTO: Road Directorate

Advanced stop line in front of a left-turn lane.

PHOTO: Road Directorate

Advanced stop line in front of a right-turn lane.

Channelisation of cyclists at junctions

At junctions with a high proportion of cyclists it can be a good idea to channel cyclists into a separate right-turn lane and a straight-on lane. The advantage is that cyclists thereby place themselves optimally before entering the junction. The lanes should be so broad that two cyclists can stop side by side, that is at least 1.85 m [122]. Without channelisation there is a risk of cyclists stopping in front of the stop line, in the pedestrian crossing and in front of the motor vehicles – and they will cycle on the footway.

If there is a right turning stage cyclists should always be channelled. With many cyclists turning right a traffic island between right turning and straight-on cyclists may be a good idea. In both signalised and priority T-crossings it is a good idea to have a left-turn lane for cyclists.

Roundabouts

Roundabouts are often used to improve road safety in Denmark, in rural as well as in urban areas. Roundabouts can also be used to reduce speed. Roundabouts often improve the traffic flow where they are used as a substitute for signalised junctions. In roundabouts the risk of accidents is low because of left turns and cross direction collisions is eliminated. Roundabouts do not always reduce the number of bicycle accidents, but generally make them less severe. For people with impaired eyesight it is especially difficult to manoeuvre in roundabouts. The major part of bicycle accidents involves entering motor vehicles.

PHOTO: Road Directorate

The two-way cycle path should cross the road further away from the roundabout or be transformed into a one-way cycle track and placed closer to the circulating lane where motorists have to give way for cyclists.

Roundabouts can be designed with one or more circulating lanes and traffic lanes in entries and exits. With more than one lane in the circulatory carriageway or entry or exit, it is not advisable to allow bicycle traffic in the roundabout. Here bicycle traffic should be led round outside the roundabout. The 3 signalised roundabouts in Denmark do not provide basis for much experience.

Cycle paths close to the circulatory carriageway where motor vehicles have to give way will not be adequate safe as motorists tend to believe that there is only one-way traffic in the roundabout.

In general, entry traffic lanes should not be broader than 3.5 m, but may be narrower for small and medium-sized roundabouts. Exit traffic lanes should not be broader than 4 m. Overrun areas with sett paving can make it easier for trucks and buses to get round.

Rural roundabouts

In the open landscape roundabouts are normally relatively dynamic, which means that circulating motor vehicles can drive relatively fast.

Cars can drive fast in this roundabout.

PHOTO: Road Directorate

This is possible where there is a large central island of 20-40 m in diameter and triangular or trumpet islands in the branches of the roundabout.

In dynamic roundabouts, bicycles should not be permitted in the roundabout itself. Instead cyclists should be led onto a path about 30 m away from the circulatory carriageway and cross the road with an obligation to give way to traffic on the road. To prevent cyclists from having to make too big a detour a two-way cycle path may be a good solution. Another solution is to lead cyclists through a tunnel at a lower level than the roundabout. This can be recommended for very busy roads with 4 or 6 traffic lanes.

Less dynamic roundabouts with a central island of 10-20 m in diameter and parallel or small triangular islands in the branches of the roundabout may be used by cyclists. In these roundabouts it is important that cyclists are led round the roundabout on a one-way cycle track, and there should be cycle tracks on entry and exit roads.

Cycle tracks and islands in less dynamic roundabouts should be designed to reduce speeds. The practice in Denmark is to establish cycle tracks next to the circulatory carriageway, and we have no experience of cycle tracks placed at a distance of 3-7 m from the circulatory carriageway. Experience from Sweden, Germany and Holland has shown that it is safer to have a shoulder of about 5 m between the cycle track and the circulatory carriageway. Bicycle traffic should be one-way and have priority over motor vehicles [12, 18, 19, 33, 136].

Roundabouts in towns

In towns speeds are lower. Roundabouts in towns are, therefore, normally smaller than in rural areas, and have a greater speed reducing effect. There are more vulnerable road users in roundabouts in towns, and this should be a basic point of departure for their design.

Cycle lanes in roundabouts should be used with caution, as the establishment of a cycle lane means an increase in the circulatory carriageway, which motorists may use to increase speed. Furthermore, without physical separation there is a risk that cyclists will be squeezed on entry and exit roads.

In roundabouts with not much traffic on roads with speed limits of 30-50 kph, cyclists should be mixed with motor vehicles in the 1-lane circulatory carriageway. Here the roundabout should have a strong speed reducing effect. The central island should have a diameter of only about 10 m, and no islands are necessary in the branches of the roundabouts. Another possibility is roundabouts on a raised surface.

In larger roundabouts with a central island of 15-20 m in diameter it may be an advantage to establish a cycle track, the best location of which is presumably 5 m from the 1-lane circulatory carriageway. If there is no space for a cycle track, and if the roundabout is used by less than about 8,000 motor vehicles per day, a possible alternative is to design the circulatory carriageway without a cycle facility or with a cycle lane and narrow circulating traffic lane. Where the traffic volume is larger, and there is not so much space – consider introducing a smaller central island or signalised junction.

In even larger roundabouts in towns with a central island of 20-30 m in diameter, traffic volumes and speeds are usually so high that bicycles should not be mixed with the motor traffic. In this case, roundabouts with one traffic lane in the circulatory carriageway and in entry and exit roads, a cycle track should be established 5-7 m from the circulatory carriageway. It may be a good idea to place this cycle track on a raised surface.

Mini-roundabouts

It is possible to drive over the central island in mini-roundabouts. The capacity for a mini-roundabout is about 15,000 motor vehicles per day. Mini-roundabouts are used where the speed limit is up to 50 kph. A mini-roundabout costs only about one tenth of an ordinary roundabout, and the inscribed circle diameter is only 15-25 m. Mini-roundabouts may with advantage be established as part of traffic calming of an area or a major road.

The priority situation must be clearly signed in the mini-roundabout. There may be road safety benefits from placing the mini-roundabout on a raised surface.

A large mini-roundabout, maybe the cycle lane brings bad luck.

PHOTO: Philip Rasmussens Tegnestue

PHOTO: Lars Bahl

Wheeling the bicycle is permitted.

idea to allow cyclists more access to pedestrian areas than is the case today.

Cyclists and pedestrian areas

Bicycle traffic is prohibited in some pedestrian areas. Where cycling is permitted in pedestrian areas, and where there is neither a cycle track nor a cycle lane, cyclists must always give way to pedestrians. Instead of totally prohibiting bicycle traffic in a pedestrian area, cycling can be permitted in certain periods, for instance, outside the opening hours of shops, when pedestrian traffic is often modest.

If there is enough room and a suitable number of pedestrians, a cycle track can be established. This reduces the number of conflicts between cyclists and pedestrians. The drawback of a cycle track is that it may be a barrier to crossing pedestrians. For mobility impaired people a cycle track is an extra barrier, while people with impaired eyesight find it easier to orientate themselves because of the separation from cyclists.

Where there is a cycle track in a pedestrian street, a change in pavement and level (2-7 cm) should make road users more aware of where they are.

In mini-roundabouts with low traffic volumes, cyclists should be mixed with the motor vehicles in the circulatory carriageway. In this case the mini-roundabout should have a very speed reducing effect. In mini-roundabouts with over 6,000-8,000 motor vehicles per day, a cycle track should be sited about 5 m from the circulatory carriageway.

Pedestrian areas and squares

In Denmark pedestrians, cyclists and motorists are often separated from each other so that each type of traffic has its own area. There are relatively few places where motor vehicles, bicycles and pedestrians share the same area. Motor vehicles and bicycles may use pedestrian streets if they show special attention and consideration to pedestrians - and always give way to them. Cyclists etc may be prohibited access to pedestrian streets by signing.

Many cyclists shop in town and are therefore cyclists as well as pedestrians. Therefore, it may be a good

PHOTO: Road Directorate

The pedestrian street is a 5-9 am short cut for cyclists.

PHOTO: Road Directorate

Two-way cycle track in a pedestrian street.

PHOTO: Lars Bahl

Do one's shopping.

Design of squares

The concept of squares covers many things – from large centrally situated squares and market places to intimate little open spaces. In connection with traffic calming there has been great interest in recreating the urban square as a meeting and market place.

Many squares have again been made wholly or partially car-free; parking spaces have been removed and new pavements and vegetation established. In most squares there are benches and possibly open air serving of food and drink, where one can sit down and have a well-deserved breather to the benefit of all.

Bicycle traffic in the square may be avoided by closing short cuts for cyclists, or making the pavement difficult to ride over, for instance, by establishing cobblestones, stairs or guard rails. The police cannot enforce a prohibition against bicycle traffic if the square is a convenient shortcut for cyclists. Regardless of whether bicycle traffic is permitted or not, it is important to establish cycle racks, thereby avoiding randomly parked bicycles.

Shared-use roads

There are many good examples of a shared-use roads in Denmark. Here pedestrians, cyclists and motor vehicles share the street, but on the premises of the pedestrians. Shared-use roads have a very low speed limit and may be a one-way street. In Denmark there are many shared-use roads that are inspired by the Dutch 'woonerf'. In Denmark the carriageway and footway must not be separated, and there must not be any through-going difference of height in the cross section of the street. The part of the road, which is suited for motor traffic may be marked, for instance, by a change in pavement.

PHOTO: Lars Bahl

PHOTO: Road Directorate

Speed reducers are necessary in some shared-use roads.

Bridges, tunnels, hills and stairs

Bridges

Especially for pedestrians, cyclists and trucks high guard rails/safety fences are necessary on bridges. Guard rails are recommended to be 1.2 m high. It must not be possible for the cyclist to slip under the guard rails.

On bridges with strong winds cyclists may derive benefit from windshields. Owing to lack of experience with windshields there are no recommended heights. Another possibility is to establish indoor cycle tracks.

Tunnels

Lighting in and outside tunnels is extremely important. Some tunnels should be lighted round the clock – it should be possible to see what is going on in the tunnel from the outside – and one should preferably be able to see through the tunnel.

Pedestrians and cyclists should always be separated in tunnels. Barriers, bollards and sharp bends should not occur inside or just outside tunnels.

Stairs

Wheeling ramps may be recommended on stairs – especially at stations, underground bicycle parking, bridges and tunnels. Almost all cyclists wheel their bicycles at their right side. Where space is narrow, it is most important to have an upward wheeling ramp. A ramp at both sides of the staircase is important so that it is easy to get up and down the staircase with the bicycle.

PHOTO: Road Directorate

Dark, narrow, sharp bend – it brings bad luck!

PHOTO: Road Directorate

Combined wheeling ramp for cyclists and prams.

At stations etc, a broad double staircase with a rail in the middle is preferable. If prams etc, are also going to use the wheeling ramp, the design must be adapted to this purpose.

The wheeling ramp should be 0.3 m broad, and the rail be placed so high up that it is not in the way of people wheeling their bicycles. In places with many cycle tourists 0.5-0.6 m broad wheeling ramps may be desirable so that it will not be necessary to take off the panniers in order to use the ramp. But do not use broad wheeling ramps on stairs

PHOTO: Road Directorate

A well-designed tunnel, but the staircase lacks wheeling ramps.

PHOTO: Road Directorate

A long walk may be the result of missing wheeling ramps.

with a modest or moderate slope because cyclists will cycle down broad ramps, and this can be dangerous.

It is possible to insert a wheel groove in the ramp, which will make it easier to wheel the bicycle. The stairs should not have a gradient of above 25 degrees – otherwise the bicycle will be difficult to wheel upwards and to control on the way down.

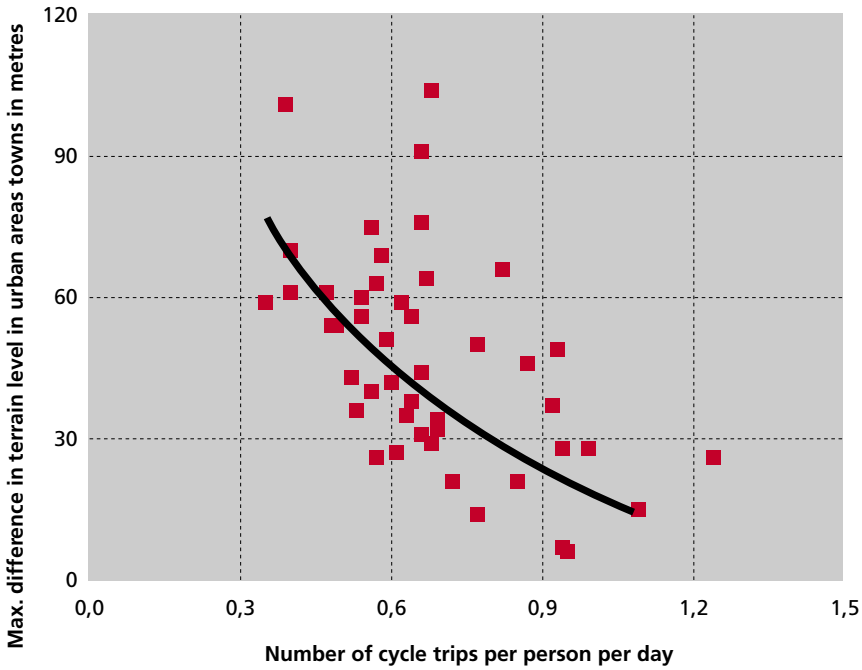
Hills

Vertical curves have previously been dealt with on page 79. But a number of other possibilities will be described here of obviating the effect of steep hills, namely fewer cyclists.

A small hill does not affect mode choice in a town, but ridges and higher hills of just 50 m have large impacts. When expanding the town, hilly areas should be avoided, and the town should be concentrated in flat areas.

PHOTO: Jens Erik Larsen

Too steep to cycle.



Relation between configuration of the ground and mode choice in Danish towns with 10,000-70,000 inhabitants. In fact, the hills is the most important factor for the number of cyclists.

With sensible planning of paths and roads even large hills can be avoided, although this will mean a minor detour. In the case of steep hills it may be sensible to sign alternative cycle routes or take refuge in expensive methods such as bicycle lifts, escalators or lifts.

One-way streets

The many traffic destinations at the centre of town make it important to be able to cycle in both directions in all streets. If only the street is sufficiently broad, two-way bicycle traffic can function in one-way streets without causing traffic flow or safety problems. Special attention should be paid to junction design.

One-way traffic in Denmark is primarily introduced in order to reduce traffic volumes by establishing one-way streets so that they meet one another or to make it possible to park. In contrast to, for instance Spain and the USA, no Danish towns have a network of one-way roads that can improve the traffic flow.

Cross section

With a special contra-flow area for cyclists, these cyclists will perhaps get to their destinations a little faster. A question still left to be answered is whether such separate areas improve the safety of cyclists as cyclists will be less alert whereas the one-way motor traffic will be more conscious of contra-flow cycling. In addition, motor vehicles passing parked vehicles may create problems for the contra-flow cycling.

In one-way streets with few cars it is not necessary to have a special area for contra-flow cyclists. In streets with more traffic, a cycle track or cycle lane may be established for contra-flow cyclists. The cycle track should be at least 1.7 m broad, while the cycle lane should be 1.5 m broad. If there is car parking just outside the cycle facility, this should be at least 2.0 m broad. It is a good idea to give the cycle facility a different pavement.

PHOTO: Municipality of Randers

With parking on the left side of the road, a cycle track or lane to the left of parked vehicles is important as motorists parked on the left side of the road have difficulty in seeing contra-flow cyclists on the right side of their vehicle.

In order to avoid illegal or undesirable parking the solution in narrow streets may be the setting up of bollards. There should be no kerbs in these streets so that cyclists find it easier to get round vehicles obstructing their way. These streets may be signed to 15 kph.

In one-way local streets that are located next to arterials and boulevards contra-flow cycling is not desirable. Here speeds and/or traffic volumes are often high.

Junctions

Especially at junctions with speeds of 40 kph or more, traffic islands and footway widenings are sensible solutions to avoid parking close to junctions and to make cyclists moving in the "wrong" direction more visible. This makes it possible for

Wide contra-flow cycle lane.

PHOTO: Danish Cyclists Federation

PHOTO: Road Directorate

Motorists are informed about contra-flow cycling.

contra-flow bicycle traffic to enter and exit the one-way street safely.

At junctions with lower speeds, signing, change in pavement and bollards may be sufficient if this in itself can prevent parking close to junctions and thus create good visibility.

Safety

A German study concludes that contra-flow cycling is safer than cycling in the direction of travelling in one-way streets [49].

Promotion

Contra-flow cycling in one-way streets clearly awards cyclists preferential treatment by giving them a shorter route than motorists. At the same time contra-flow cycling, which takes place every day, irrespective of any prohibition, is legalised.

The traffic island prevents parking close to the junction.

PHOTO: Road Directorate

Traffic control measures

Permanent road closure

Road closures are carried out in Denmark primarily to avoid through-going motor traffic. Road closures are increasingly being used in order to reduce the total volume of motor traffic in town centres and to improve road safety. When urban areas are divided into zones by means of road closures, short car trips become less attractive.

Road closures are most often carried out in connection with junctions. Remember that motorists have a need to turn at one or both sides of the road closure, and this poses certain design requirements. To avoid irritating turning manoeuvres, the cul-de-sac sign should be visible.

It should be easy to cycle through a road closure as the purpose of road closures is only rarely to prevent cyclists from passing through. Cyclists ought to be able to pass through two openings, each 1.3-1.4 m broad. One idea may be to establish the cycle gaps just beside each other with a removable bollard as separation, thus making it easier to clean and maintain the area of the road closure. It is extremely important not to have parking in front of the cycle gap.

Planting vegetation, bollards or high kerbs without asphalt slopes emphasize the purpose of the road closure.

Intelligent/time-controlled road closure

In central urban areas the town environment would be considerably improved, if commuters did not enter the area by car, and through-going motor traffic was made impossible. With bollards that can be raised and lowered and access

PHOTO: Road Directorate

The street was fully reconstructed into playground and cycle-footway.

PHOTO: Road Directorate

Cyclists can easily passage this road closure.

PHOTO: Road Directorate

Bicycle racks is part of the road closure.

cards, unwanted motorists can be kept out from an urban area. Access cards may be given to residents, ambulances, police, refuse collection, shopkeepers etc.

By lowering the bollards for some hours every day, vehicles will be able to deliver goods to shops and companies. Conversely, the bollards may be raised during the periods when most people are on their way to work. Exits from the area should be designed so that it is always possible to leave by vehicle. Thus nobody are trapped, and it will be easier for vehicles to leave the area.

Bus gate

Just as in the case of road closures, the purpose of the bus gate is to reduce motor traffic and thereby give higher priority to pedestrian, bicycle and bus traffic. The bus gate can contribute to the bus plan being kept without delays. The bus gate can of course be made intelligent/time-controlled just like road closures.

The simple bus gate just signs the prohibition to enter for other motor traffic. Physical barriers to other traffic such as barriers, which can be raised/lowered by activating a transmitter in the bus, are often necessary. Another and often better possibility is a lane width obstruction, whereby only broad vehicles can pass at low speed. Bus gates should always be equipped with 1.3-1.4 m broad cycle gaps at both sides of the road.

Other gates, for instance, for trams, trucks etc, may also be established, but always remember the cycle gaps.

Regulating parking

In locations where there is a great need for stopping or parking, signs prohibiting stopping or parking are sometimes not sufficient.

PHOTO: Road Directorate

Lane width obstruction and cycle gates.

PHOTO: Road Directorate

This truck gate is difficult to pass for cyclists without illegally cycling on the footway.

PHOTO: Road Directorate

Cycle track with illegal chicanes.

Many motorists know that they must not park less than 10 m from a junction in Denmark, but they park illegally without realising it as the parking prohibition is rarely marked. Discreet but visible marking is preferable.

Parking is illegal on cycle tracks and cycle lanes and is at the same time regarded negatively by cyclists [114]. Parking on narrow roads with much traffic, double parking and parking on cycle tracks and lanes can make cycling very risky.

Double parking can be avoided by narrowing the street or introducing time-limited parking. Taxi stands at large hotels, traffic terminals, pedestrian streets and restaurants, cafes, night clubs and pubs etc, can in many cases be a good solution. Kiss-and-ride places at schools, traffic terminals etc, may also be necessary.

In shopping streets the argument of shopkeepers is often to allow parking since unloading of goods always is necessary. One possibility is to allow parking only for the unloading of goods outside relevant shops. Parking to unload goods should take place at specially prescribed places, which can otherwise be used as pedestrian areas.

20-25 cm high kerbs or bollards are a last resort to avoid illegal stopping and parking. Bollards and high kerbs can make cyclists feel unsafe and increase the risk of single accidents with fixed objects. Therefore, a good distance should be ensured – at least 30 cm – between bollards and cyclists, and road safety should be closely considered.