Road engineering measures for cyclists

effects on safety and perceived safety

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Road engineering measures for cyclists: effects on safety and perceived safety

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Preface

This booklet summarises the effects of 12 selected road engineering measures that aim to improve cyclists' safety, perceived safety and "passability" while cycling.[1)] Passability is seen as the speed and ease with which cyclists can travel, and the degree to which their passage is impeded or helped by the conditions on the road. The summary is based on a comprehensive review of the experience, evaluations and recommendations that have appeared in Danish and other international literature over the past 20 years.

The purpose of the booklet is to strengthen the role of road and traffic planners in enabling more people to choose to cycle rather than use a car, and to make these journeys safer. The booklet was first published in 2020, and this updated version contains two new chapters covering urban roundabouts and protected junctions.

Danish Road Directorate, February 2023

Definitions of effects

	**Positive effect:** It is well documented that the measure has a positive effect, and that the size of the effect is known.
	**Likely positive effect:** Experience/indirect investigations suggest that the measure has a positive effect. The size of the effect is unknown.
	No/uncertain/depending effect: 1. It is documented that the measure has no impact. 2. Studies suggest ambiguous impacts. 3. The impact depends on a) type of measure or b) standard of comparison (before/without design).
	**Likely negative effect:** Experience/indirect investigations suggest that the measure has a negative effect. The size of the effect is unknown.
	**Negative effect:** It is well documented that the measure has a negative effect, and that the size of the effect is known.

1) The effects on accidents of the 12 selected measures cover accidents involving personal injury and accidents with only property damage. Effects for other road user groups are not described. More information about the detailed design of the various solutions can be found in the Danish road standards.

Contents

Introduction

Denmark aims to encourage cycling, and to do this, road planners must consider the safety and perceived safety of cyclists when designing roads and road safety measures.

Road safety for cyclists can be quantified by the number of fatalities and injuries among cyclists on the road. By contrast, cyclists' perceived safety is their own, subjective and qualitative sense of safety when moving in traffic, and what they personally experience intuitively and emotionally. This sense of (in)security may affect their choice of means of transport and routes. A high degree of perceived insecurity may make a cyclist less prone in the future to choose the same route again, or even to cycle again. Insecure road users (who in general already feel exposed in traffic, such as elderly cyclists), may more easily feel unsafe.

As traffic planner, it might be assumed that implementing proven road safety measures – and then communicating this to cyclists – will automatically make cyclists feel safe on the roads. But this is far from the case. Often, when improving cycling opportunities, it is necessary to balance road safety and perceived safety.

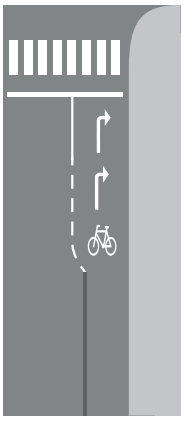
This booklet provides an overview of 12 different road engineering measures. Each measure (and variations thereof) is evaluated in relation to cyclists' safety, cyclists' perceived safety and cyclists' passability. When designing such interventions (e.g. a road or a junction), it is always necessary to perform an assessment of the actual conditions.

1 Truncated cycle track at signal-controlled junctions

1.1 Description of the measure

A truncated cycle track or cycle lane is one that terminates at the start of a signal-controlled right-turn lane, typically, 15–25m before the junction. Once the lane is truncated, cyclists and mopeds must continue into the right-turn lane and merge (share the lane) with right-turning vehicular traffic. The lane should be marked with right-turn arrows and a cycle symbol.

The idea of a truncated cycle track is to draw the attention of drivers and cyclists to each other before the junction, by bringing the road users closer together at the same level and thereby decreasing the number of bicycle accidents.



1.2 Effects on road safety and perceived safety

	Effects for cyclists
Safety	
Perceived safety	
Passability	

Road safety

Truncated cycle tracks are proven to benefit cyclist safety at signal-controlled junctions. A recent and robust Danish study found that altering a full-length (i.e. non-truncated) cycle track to a truncated cycle track reduces the number of bicycle and moped accidents by about 60 % in the approach to a junction, while introducing a truncated cycle track where there previously was no cycle track reduces the number of bicycle and moped accidents by about 50 %. These effects relate to accidents with right-turning vehicles, accidents with left-turning vehicles from the opposite side of the road, and side-by-side collisions in the approach to the junction.

Before-situation	After-situation	Effects on bicycle and moped accidents*
No cycle track or lane	Truncated cycle track	Number of accidents reduced by 50 %
Full-length cycle track next to a combined straight-ahead and right-turn lane for vehicles	Truncated cycle track	Number of accidents reduced by 60 %
Full-length cycle track next to a dedicated right-turn lane for vehicles	Truncated cycle track	Number of accidents reduced by 60 %

** These effects relate to accidents with right-turning vehicles, accidents with left-turning vehicles from the opposite side of the road, and side-by-side collisions in the approach to the junction.*

Perceived safety

Generally, relative to full-length cycle tracks and lanes, truncated cycle tracks increase cyclists' sense of insecurity, while the effect is minimal in situations where previously there were no bicycle facilities. This increased sense of insecurity can be explained by cyclists having to mix with vehicular traffic. In particular, this may be challenging for insecure cyclists such as children and elderly people.

Traffic flow and other effects

Compared to full-length cycle tracks (and lanes), truncated cycle tracks reduce cyclists' passability, since cyclists do not have a dedicated area. In some cases they have to give way to cars when merging, and may get stuck behind large, slow-moving vehicles making right-hand turns.

1.3 Recommended use

Truncated cycle tracks are preferred to full-length or no cycle tracks from a road safety point of view. The measure may cause a reduced perceived safety compared to full-length cycle tracks – in particular for insecure cyclists. The measure is particularly relevant if:

- There are a lot of mopeds, e-bikes, speed pedelecs or cycle commuters at high speed.
- The road continues downhill, meaning cyclists will be travelling at greater speed.
- Space is limited.
- There is no need for cycle signals.

1.4 Further reading

Berg, S. T. (2019). Afkortede cykelstier - religion eller trafiksikkerhed, Trafikdage, AAU.

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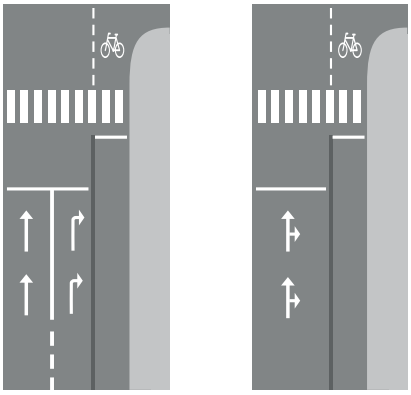
2 Full-length cycle track at signal-controlled junctions

2.1 Description of the measure

A full-length cycle track is a traditional cycle track (or cycle lane) that continues through to the junction and is located on the right-hand side of the vehicular traffic lane. Often a full-length cycle track is combined with an advanced stop line of 5m for cyclists. The measure has two main types:

- Full-length cycle track next to a dedicated right-turn lane for vehicles.
- Full-length cycle track next to a combined straight-ahead and right-turn lane for vehicles.

The intention of a full-length cycle track is to ensure good passability and a high level of perceived safety for the cyclists by allowing them their own track through to the junction. In addition, safety features such as an advanced stop line for cyclists and possibly a cycle signal may be present, making it easier for right-turning vehicles and left-turning vehicles (from the opposite side) to see cyclists who are travelling straight ahead.



2.2 Effects on road safety and perceived safety

	Effects for cyclists	
	Full-length cycle track next to a dedicated right-turn lane for vehicles	Full-length cycle track next to a combined straight-ahead and right-turn lane for vehicles
Safety	😐	☹
Perceived safety	☺	☺
Passability	☺	☺

Road safety

The effect of a full-length cycle track on road safety depends on whether the measure is located next to a dedicated right-turn lane for cars or next to a combined straight-ahead and right-turn lane. It also depends on the other solutions with which the intervention is compared.

A full-length cycle track next to a dedicated right-turn lane is significantly safer than a full-length cycle track next to a combined straight-ahead and right-turn lane. Redesigning the lane by changing from a combined straight-ahead and right-turn lane for vehicles to a dedicated right-turn lane for vehicles thus reduces the number of bicycle and moped accidents by about 50 % in the approach.

Redesigning approaches to junctions that have no bicycle facilities to include a full-length cycle track with a dedicated right-turn lane appears to have no effect on road safety. By contrast, establishing a full-length cycle track with a combined straight-ahead and right-turn lane instead will increase the number of bicycle and moped accidents by about 130 %.

Older studies have found that there is no notable difference in the safety level of approaches to junctions that have a full-length cycle track or those that have a truncated cycle track. Recent studies find that establishing a full-length cycle track (both variants) at an approach that previously had a truncated cycle track will lead to a significant 200-250 % increase in the number of cycle and moped accidents.

Before-situation	After-situation	Effects on bicycle and moped accidents*
No cycle track or lane	Full-length cycle track next to a dedicated right-turn lane for vehicles	No change
No cycle track or lane	Full-length cycle track next to a combined straight-ahead and right-turn lane for vehicles	Number of accidents increased by 130 %
Truncated cycle track	Full-length cycle track next to a dedicated right-turn lane for vehicles	Number of accidents increased by 200 %
Truncated cycle track	Full-length cycle track next to a combined straight-ahead and right-turn lane for vehicles	Number of accidents increased by 250 %
Full-length cycle track next to a combined straight-ahead and right-turn lane for vehicles	Full-length cycle track next to a dedicated right-turn lane for vehicles	Number of accidents reduced by 50 %

** These effects relate to accidents with right-turning vehicles, accidents with left-turning vehicles from the opposite side of the road, and side-by-side collisions in the approach to the junction.*

Perceived safety

A full-length cycle track improves cyclists' perceived safety compared to an approach with a truncated cycle track or no bicycle facilities at all. This is due to the cyclists having a dedicated area which is physically separated from carriageway and pavement.

Passability and other effects

The measure also improves passability for cyclists compared to junction approaches that have truncated cycle tracks or no bicycle facilities at all, since the cyclists have a dedicated area physically separated from vehicular road lanes and the pavement.

2.3 Recommended use

A full-length cycle track next to a combined straight-ahead and right-turn lane is, from a safety point of view, not the best solution for the cyclists. Full-length cycle track next to a dedicated right-turn lane is better from a safety point of view and may be used in an approach where perceived safety and/or traffic flow is particularly important to cyclists. Full-length cycle tracks cause more accidents, and they are more space-consuming than truncated cycle tracks and less suitable when cyclists travel at high speed.

2.4 Further reading

Berg, S. T. (2019). Afkortet cykelstier - religion eller trafiksikkerhed, Trafikdage, AAU.

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Jensen, S. U. (2006). Cyklisters oplevede tryghed og tilfredshed, Trafitec.

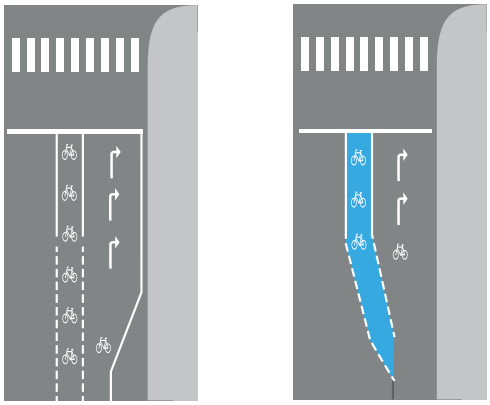
3 Cycle lane between straight-ahead and right-turn lanes

3.1 Description of the measure

This type of cycle track/lane continues as a marked cycle lane between a straight-ahead lane and a right-turn lane for vehicular traffic (i.e. to the left of the right-turn lane). The cycle lane is marked with cycle symbols and is eventually coloured blue, while the right-turn lane is marked with turn arrows and possibly also with cycle symbols (if intended for right-turning cyclists as well).

The cycle lane should have a minimum width of 1.5m, including the edge line adjacent to straight-ahead lanes for vehicles, and the width of the right-turn lane should be 3.5m. There should be a section where right-turning vehicles can cross the cycle lane to the right-turn lane.

The aim of this measure is to replace the hazardous conflicts between right-turning motor vehicles and straight-ahead cyclists with less-hazardous “merge situations” before the actual junction. At the same time, the straight-ahead cyclists become more visible for the left-turning motor vehicles from the opposite side. Finally, the purpose is to provide better traffic flow for straight-ahead or left-turning cyclists and more space compared to a traditional truncated cycle track.



3.2 Effects on road safety and perceived safety

	Effects for cyclists
Safety	
Perceived safety	
Passability	

Road safety

While the measure is recommended and is used as a traffic safety measure in many countries, only a few studies from Denmark and Norway have investigated the safety effect. These studies provide no unambiguous conclusions, but they do not seem to suggest that the measure causes more bicycle accidents. Other studies that have indirectly investigated the effect find that the measure probably has a positive safety effect.

Compared to a truncated cycle track, the measure will probably decrease cyclists' safety, but this has not been investigated.

Based on the studies, it is not possible to quantify the size of the effect.

Perceived safety
It is inconclusive as to whether the measure has a positive or negative effect on cyclists' perceived safety. The effect depends on the before-situation. If the before-situation is a full-length cycle track/lane, the measure can increase the sense of insecurity. Merging with vehicles before the junction and having cars, lorries and buses on both sides of the cyclist may make cyclists feel insecure.

If, on the other hand, the cyclists in the approach already travel on the roadway or on a truncated cycle track, the marked cycle lane will make them feel more safe. This is due to the fact that part of the roadway is dedicated to the cyclists.

Passability and other effects
The measure probably improves cyclists' passability. Firstly, the measure provides cyclists with better options for overtaking any queue of vehicles before the intersection. Secondly, it will encourage more people to cycle on the carriageway rather than illegally on the pavement (to the extent that this occurs), which improves passability for cyclists.

Generally, the measure is considered an improvement among cyclists if the alternative is a truncated cycle track where cyclists mix with vehicular traffic.

3.3 Recommended use

The measure can solely be used in signal-controlled junctions, where there is a dedicated right-turn lane, and typically it will be established where a truncated cycle track exists. It should be ensured that merging with vehicles happens at low speed, thus making it most suitable for junctions with speed limits not exceeding 50km/h.

3.4 Further reading

Høye A., Sørensen M. W. J. og de Jong T. (2015). Separate sykkelanlegg i by - Effekter på sikkerhet, fremkommelighet, trygghetsfølelse og transportmiddelvalg, TØI.

Nielsen, M. A. (1995). Cykelbane på venstreside af højresvingsbane, Dansk Vejtidsskrift.

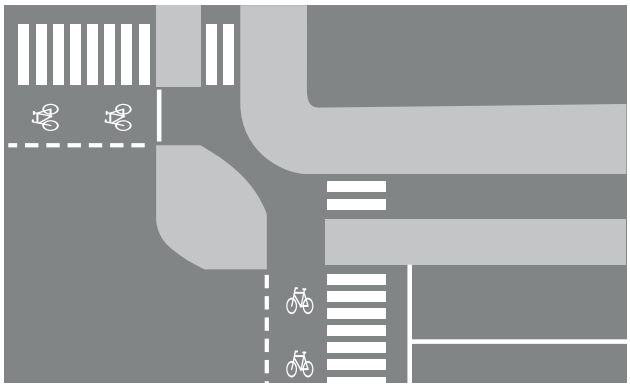
Sørensen, M. W. J. (2010). Midtstilt sykkelfelt i Oslo - Effekt på syklisters sikkerhet, trygghet og atferd, TØI.

4 Protected junctions

4.1 Description of the measure

A protected junction (also known as a “Dutch design”) is where the cycle track continues all the way up to the stop line at a signal-controlled junction, after which the cycle track continues around the corner of the junction. The cyclists then cross the intersecting road next to the pedestrian crossing. The measure may involve a coloured surface denoting the area dedicated to cyclists.

The purpose of this solution is to place cyclists ahead at the junction to make them more visible to turning drivers. And the fact that they are crossing the junction next to pedestrians can help raise drivers’ awareness of – and caution around – all non-motorised road users at the junction.



4.2 Effects on road safety and perceived safety

	Effects for cyclists
Safety	😐
Perceived safety	😐
Passability	☹

Road safety

The solution is widespread in the Netherlands and there are also examples of it in the UK, USA and Denmark. While there are only a few minor or methodically insufficient studies that examine the safety effect, they nevertheless suggest similar findings – that as a minimum, the measure does not worsen cyclists’ road safety compared to a traditional full-length cycle track. Based on available studies, it is not possible to quantify the size of the effect.

Having said that, the greater cyclist visibility afforded by protected junctions because they are ahead of vehicular traffic at the junction, and the fact that they have less far to travel to cross it, are positive factors for cyclists’ road safety.

Perceived safety

The effect on perceived safety has not been directly investigated. Empirically and theoretically cyclists may find the solution safer than a traditional full-length cycle track, since it can provide better visibility conditions as well as an even higher degree of physical separation and distance between

cyclists and vehicles. Left-turning cyclists may also experience a higher level of perceived safety as they are able to await green light in the new direction of travel behind a traffic island instead of having to wait unprotected at the junction immediately next to the vehicles.

On the other hand, perceived safety might be reduced for cyclists arriving at a green light and who are going straight ahead, as it is difficult to signal going straight ahead to drivers. Actually, the cyclist's first movement could indicate that the cyclist will make a right turn. This problem can be particularly relevant in compact junctions.

Passability and other effects
The effect on passability is not directly examined either. The measure may have both positive and negative effects for cyclists depending on the manoeuvre, the density of traffic, and the junction design itself. Cyclists' passability is affected positively if the cyclists are able to bypass a red signal because they are turning right and not travelling straight ahead.

Waiting cyclists may however block the passage for right-turning cyclists and for cyclists in the transverse direction. This applies in particular if it is a compact junction at places with dense bicycle traffic. Likewise, the left-turning cyclists' waiting time will be longer as they must await green light in the new direction of travel, whereas in a traditionally designed junction, they would be able to finish their left turn without taking the signals into account.

For cyclists going straight ahead, the measure may result in a short detour and if they arrive during a green light, the s-curve through the junction can, depending on the specific layout, result in considerably reduced speed. Cyclists arriving during a red light, and going straight ahead, may stand a little further ahead in the junction while waiting for green.

The layout can be more space consuming than junctions with a traditional full-length cycle track, especially in case of dense cycle traffic where you have to avoid a scenario in which different cycle flows block each other.

4.3 Recommended use

In theory, the measure can be established in all signal-controlled junctions with a cycle track but will be more space consuming in its ideal layout than a traditional junction. In Denmark, the measure is found only in a few locations, e.g. Viborg, Juelsminde, Skanderborg, Virum, Lyngby and Aalborg. The solution is typically established where there had previously been a full-length cycle track.

4.4 Further reading

Beelen, V. J. H. (2015). Bicycle friendly junction designs: A comparison between two junction types. www.utwente.nl.

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5 Two-way cycle paths at junctions

5.1 Description of the measure

Two-way cycle paths through junctions pose a special challenge and so they should, if possible, be constructed as a **grade-separated crossing**. Where this is not possible, junctions should be signal-controlled or be priority T-junctions.

In **signal-controlled junctions**, two-way cycle paths should be handled by separate control with a dedicated cycle phase to avoid conflicts of duty to give way concerning right- or left-turning vehicles. A two-way cycle path should never be truncated at the junction and have a maximum width of 3m at the junction. There must be at least 0.5-1m between path and roadway.

In **priority T-junctions**, the following three solutions are recommended:

- "Give way" line on the secondary road behind intersecting path.
- The duty to give way is imposed on the cyclist.
- "Give way" lines on the secondary road before the cycle path and before the primary road.

Clear indication of the duty to give way is important, and cyclists' duty to give way can be emphasised by the establishment of traffic-calming measures on the path such as a raised surface. If cyclists have the duty to give way, the gap between the two-way cycle path and the primary road should be a minimum of 6m.

The shaping and the effects of the two-way cycle paths on sections with roundabouts are not dealt with in this booklet.

5.2 Effects on road safety and perceived safety

	Effects for cyclists		
	Signal-controlled junctions: separate control	Priority T-junctions: duty to give way is imposed on the vehicle	Priority T-junctions: duty to give way is imposed on the cyclist
Safety			
Perceived safety			
Passability			

Road safety
Where road safety is concerned, two-way cycle paths are problematic at junctions, mainly because drivers (both crossing, right-turning and left-turning from the opposite side) do not always consider cyclists approaching from what they may perceive as the “wrong” direction. Right-turn motorists also find it difficult to notice cyclists coming from behind in the same direction because they are too far from the roadway.

Signal-controlled junctions with a two-way cycle path should have separate control with a dedicated cycle phase as this separates vehicle and cyclist traffic.

Two-way cycle paths in priority junctions are unsafe, and for this reason the measure should only be implemented in T-junctions. Studies show that there is a high risk of accidents, especially for cyclists approaching in the “wrong” direction.

In order to improve the road safety in priority T-junctions, imposing the duty to give way on cyclists or establishing an extra give-way line on the side road may be very effective measures. Further, or alternatively, raised surfaces as well as improved markings and signposts can contribute to increase the safety.

Perceived safety
The influence on perceived safety of a dedicated cycle phase in signal-controlled junctions with two-way cycle paths has not been investigated. However, it is probable that this measure has a positive effect due to the fact that cyclists have their own green-light phase (reducing conflict with vehicular traffic) – especially at complex junctions.

Cycling on two-way cycle paths in priority T-junctions is assumed to give rise to a certain sense of insecurity for cyclists approaching in the “wrong” direction, since they cannot be sure whether intersecting drivers have seen them. Coloured surfacing, road marking and signposting at the junction can minimise the sense of insecurity.

Passability and other effects
Typically, dedicated phases in a signal-controlled junction will reduce the total capacity of the junction, and any limited green time for the cyclists will cause increased delay and thus poorer accessibility for the cyclists.

Imposing the duty to give way on cyclists, and the possible addition of traffic-calming measures at priority T-junctions will reduce the passability for cyclists.

5.3 Recommended use

Two-way cycle paths are not suitable along roads where there are many side roads or entrances and exits across the path, since drivers are not always paying attention to the fact that cyclists may approach in the “wrong” direction.

Two-way cycle paths in four-way junctions should be signal-controlled, while two-way cycle paths in priority T-junctions can work (roundabouts are not dealt with here). In priority junctions, cyclists should have the duty to give way from a road safety point of view. Solutions in which vehicular traffic has the duty to give way is only recommended where there is limited traffic on the side road, or where the cyclists’ passability needs prioritising.

5.4 Further reading

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6 Cycle signals at junctions

6.1 Description of the measure

Cycle signals can be used at approaches to signal-controlled junctions that have full-length cycle tracks or lanes. The measure is found in a range of types, including:

- **Separate control:** Separate signal phase for cyclists. The intention is to obtain conflict-free control of cyclists and vehicular traffic.
- **Early release:** Cyclists waiting at the stop line are released by a green signal a few seconds before the vehicular traffic. The intention is to give cyclists the opportunity to proceed earlier and be in the middle of the junction by the time the right-turning vehicular traffic is released.
- **Early red:** Cyclists get a red signal a few seconds before the vehicular traffic. The intention is to stop the cycle traffic, whereby right-turning vehicular traffic can be completed.
- **Right-turn arrow:** Division of a cycle track into a straight ahead and a right-turn lane with a three-section cycle signal and a one-section right-turn cycle signal. The intention is that vehicular and cycle traffic can turn to the right at the same time.

6.2 Effects on road safety and perceived safety

	Effects for cyclists			
	Separate control	Early release	Early red	Right-turn arrow
Safety				
Perceived safety				
Passability				

Road safety

Preventing conflict between cycle and vehicular traffic at signal-controlled junctions using separate control with a dedicated cycle phase provides the best solution from a safety point of view (together with a grade-separated crossing). Using this measure, signal-controlled right turns reduce the number of right-turn accidents by about 75 % compared to signal-controlled junctions without a separate right-turn phase.

Before-situation	After-situation	Effects on bicycle and moped accidents*
Signal-controlled junctions with a separate right-turn phase	Signal-controlled junctions without a separate right-turn phase	Number of accidents reduced by about 75 %

** These effects relate to accidents with right-turning vehicles in the approach to the junction.*

For cyclists, an early-release green light means that after a red signal, cyclists can move into the intersection sooner and thus become more visible to right-turning cars, buses and lorries. This likely contributes to reducing the number of right-turn accidents.

An early red light for cyclists may contribute to preventing right-turn accidents as they give

right-turning vehicles more time to turn without getting into conflict with cyclists travelling straight ahead. The measure also ensures that cyclists have better time to pass the junction before road users crossing from side roads get a green signal, which improves safety. However, behavioural studies show that cyclists have less respect for cycle signals than main traffic signals.

Perceived safety
The effect of cycle signals in relation to perceived safety has not been investigated. However, it is estimated that a dedicated cycle phase, with great probability, has a positive effect as a result of the time separation it offers cyclists from vehicular traffic.

Early release increases cyclists' visibility and thus drivers' attention to them, which may slightly increase cyclists' perceived safety.

Early red lights and right-turn arrows probably have no or only limited importance.

Passability and other effects
Concerning passability, the effect of dedicated cycle phase depends on the actual signal plan, and whether cyclists overall get more or less green time. However, the total capacity of the junction will typically be reduced.

For cyclists, early release and early red lights may result in a minor either improvement or reduction of passability due to either longer or shorter green time. At the same time, this may give the cyclists a sense of being either more or less prioritised compared to vehicular traffic.

Right-turn arrows will improve the passability for right-turning cyclists.

6.3 Recommended use

Cycle signals may be used in signal-controlled junctions with a full-length cycle track/lane. A dedicated cycle phase and an early release and right-turn arrow may be used at junctions where cyclist priority is requested, and/or where – due to road safety concerns – there is a need for time separation of cyclists and vehicular traffic.

6.4 Further reading

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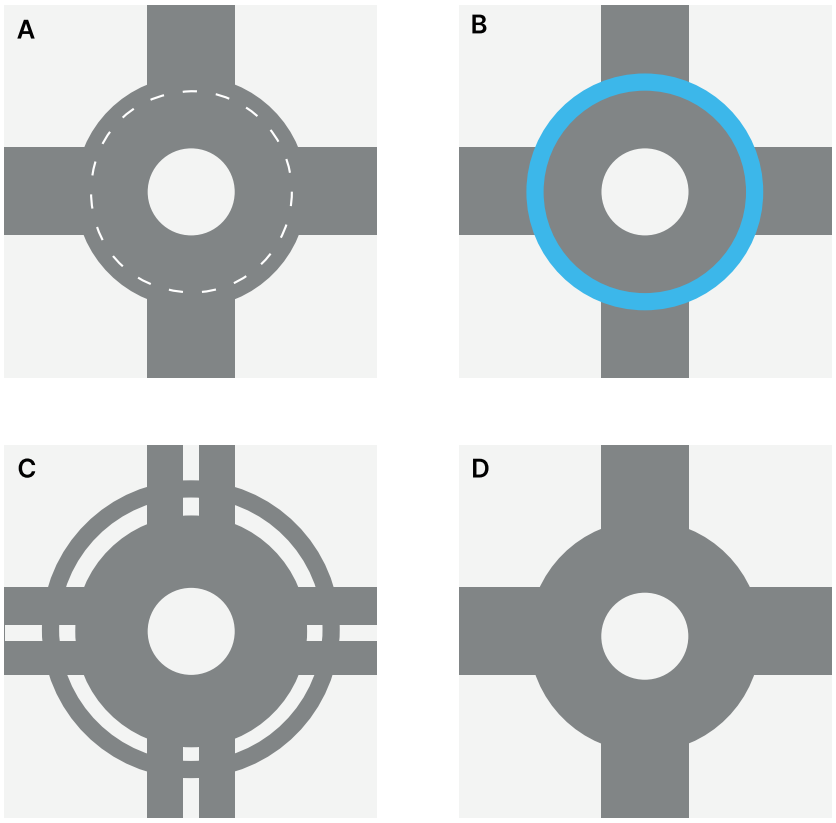
7 Bicycle facilities at urban roundabouts

7.1 Description of the measure

Most urban roundabouts in Denmark are mini- or single-lane roundabouts. Two-lane roundabouts are rare and cyclist should be cyclists prohibited unless a grade separated crossing is present, or alternatively a setback cycle path outside the roundabout where cyclists have duty to give way when crossing approach and exit lanes. In mini- and single-lane roundabouts, cyclists are accommodated through:

- **Cycle track at the roundabout (A)**, where the cycle track is constructed around the roundabout.
- **Cycle lane at the roundabout (A)**, where the cycle lane is marked out on the roundabout.
- C**oloured markings (B)**, where a cycle track or lane is marked in blue.
- **Setback cycle path outside the roundabout (C)**, where the cycle track is set back by 10-15 metres from the roundabout and cyclists are required to give way when crossing the approach and exit lanes.
- **No bicycle facility at the roundabout (D)**, where all cycle tracks truncate before the roundabout, and cyclists must ride alongside vehicular traffic on the roundabout.



7.2 Effects on road safety and perceived safety

	Effects for cyclists				
	Cycle track at the roundabout	Cycle lane at the roundabout	Coloured markings	Setback cycle path outside the roundabout	No bicycle facility at the roundabout
Safety					
Perceived safety					
Passability					

Accommodation for cyclist	Risk of accident: Bicycle and moped accidents (with/without injury) per mill. cyclist *
Cycle track at the roundabout, no coloured marking	1,3
Cycle track at the roundabout, all	1,6
Cycle track at the roundabout, coloured marking	1,8
Cycle lane at the roundabout, no coloured marking	2,0
Cycle lane at the roundabout, all	2,1
Cycle lane at the roundabout, coloured marking	2,2
Setback cycle path outside the roundabout	0,5
No bicycle facility at the roundabout	0,9
On average	**1,7**

** The risk of accident is stated per bicycle and not per vehicle. Some of the differences in risk of accident can consequently be explained by the fact that type of accommodation for cyclists often also depend on vehicular traffic volumes.*

Road safety

Cyclists' use of roundabouts poses a challenge to road safety. The safest option is complete separation of cyclists from vehicular traffic by establishing a cycle path outside the roundabout. The next-best option is complete integration with vehicular traffic and no bicycle facility at the roundabout. In relation to the average risk of accidents for bicycle and moped accidents at urban roundabouts, compared to the standard risk of Option A (above) with a cycle track, the risk is reduced by two thirds when using Option C and is halved when using Option D.

Cycle lanes at roundabouts provide the worst safety, and, to some degree, also cycle tracks. The risk of accidents for bicycles and mopeds is about the same in roundabouts with a cycle track as in urban roundabouts overall, while in roundabouts with a cycle lane it is 20-30 % higher. The risk of accidents is at its highest if the cycle lanes and cycle tracks are coloured (e.g. blue), in which case the risk of accidents rises by about 10 % and 40 %, respectively.

In addition, roundabouts with traffic calming measures, few (or no) pedestrian crossings, and few and only perpendicular road entries and exits radiating from it provide the lowest risk of bicycle and moped accidents. In practice, it can be challenging to secure few and perpendicular exits as roundabouts are often established at locations where multiple and non-perpendicular roads intersect.

Perceived safety
A high degree of separation between bicycle and vehicular traffic – e.g. a setback cycle path outside the roundabout or a cycle track at the roundabout – gives a higher level of perceived safety to cyclists. This is because cyclists get a dedicated area physically separated from the carriageway and pavement through a kerb or verge, etc. When there is a cycle lane at the roundabout, separation from the carriageway is not physically established but is only visible by markings, which reduces the perceived safety accordingly.

Generally, a cycle track or lane marked in blue will increase cyclists' perceived safety, as it highlights the bicycle area and allows cyclists to feel more prioritised.

Roundabouts with no bicycle facilities provide a greater sense of insecurity among cyclists as they have to mix with and share the road with vehicular traffic. This may be particularly challenging for insecure cyclists such as children and elderly people, and especially if there is high speed or heavy traffic, narrow lanes, or cycle track or lanes that truncate just before the roundabout.

Passability and other effects
A setback cycle path outside the roundabout provides the poorest passability for cyclists since they often have to make detours and have a duty to give way. However, in the case of a two-way setback cycle path, left turning cyclists may get a short cut.

Cycle tracks and cycle lanes provide the best passability for cyclists as they usually provide the shortest route through the roundabout, and vehicular traffic approaching and exiting the roundabout has a duty to give way to cyclists.

No cycle tracks or lanes at a roundabout also means cyclists can take the fastest route through the roundabout - however, cyclists will not have a dedicated area and may risk a dense vehicular traffic jam that delays their entry into the roundabout and obstructs them when they are on the roundabout itself.

Cycle lanes and tracks coloured blue have no negative impact on passability, and there is a chance that they may help it a bit.

7.3 Recommended use

Roundabouts pose a challenge to urban cyclists. Signal-controlled junctions are often safer for them, especially compared to traditional roundabouts with a cycle track or lane.

A roundabout with a setback cycle path outside it, and roundabouts with no cycle lanes or tracks at all, provide the best safety for cyclists, though these reduce passability and lower perceived safety, respectively. Choosing a solution requires prioritising safety, perceived safety and passability for cyclists. Space requirements are a factor in this equation, as a roundabout with a setback cycle path outside it is more space consuming than the other alternatives, and in urban areas it may prove difficult to acquire enough space for such a solution.

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8 Bicycle facilities at bus stops

8.1 Description of the measure

On roads with a ***cycle track***, bus stops are typically established as the following:

- **Bus stop with a wide island** between the cycle track and the carriageway, where waiting passengers can stand and where passengers can exit buses.
- **Bus stop with a narrow island** between the cycle track and the carriageway, where the waiting area on the pavement is supplemented with a small area to await, board or exit the bus.
- **Bus stop on pavement**, where passengers awaiting the bus can stand on the pavement and board the bus from the cycle track, and where alighting passengers must exit directly onto the cycle track.

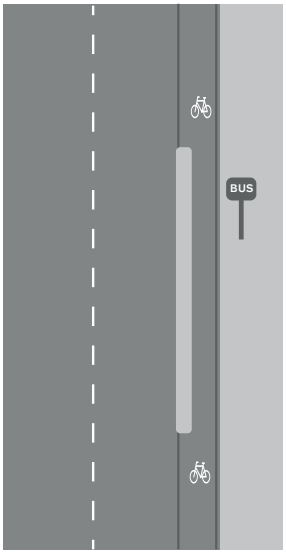
On roads with ***cycle lanes***, the following solutions are typically established in connection with bus stops:

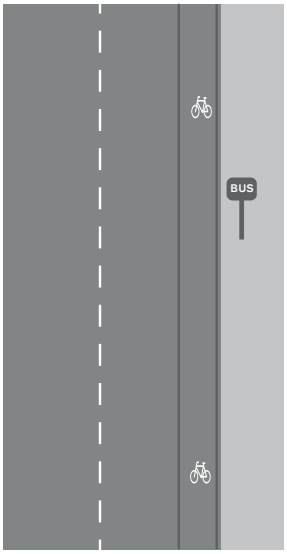
- **Reinforced cycle lane**, where the cycle lane is upgraded to a cycle track around a bus stop, and the above cycle track solutions are used for these upgraded stretches.
- **Bus stop on pavement**, where the bus pulls in at the stop and stands in the cycle lane, forcing cyclists to wait behind the bus.
- **Bus stop in bus bay**, where the cycle lane runs on the left side of the bus bay.

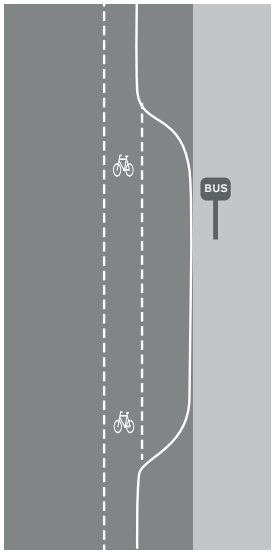
On roads with ***no bicycle facilities***, the bus stop is typically established at the kerbside, where cyclists have to wait behind the standing bus.

The bus stop can, independent of any cycle solution, be placed in the middle of the road, but this is often only seen regarding BRT routes (Bus Rapid Transit).

Upon establishment of a bus island, it is important that it is wide enough for passengers to enter, exit and look both ways without getting involved in conflicts with cyclists.







8.2 Effects on road safety and perceived safety

	Effects for cyclists		
	Bus stops next to a cycle track (no bus island)	Bus stops next to a cycle lane (no bus island)	Bus island
Safety			
Perceived safety			
Passability			

Road safety
Bus stops on roads with cycle tracks or lanes pose a challenge to road safety, especially in relation to conflicts and accidents between passengers and cyclists. The risk of accidents is particularly high for two-way cycle paths. Generally, bus islands reduce the risk of such accidents.

Many passengers and cyclists do not know the give-way rules at bus stops (passengers have a duty to give way when there is a bus island, while cyclists have a duty to give way when there is no bus island). This lack of knowledge poses a huge safety problem.

Foreign studies find that in general the fewest cycle accidents occur at bus stops located in the middle of the road. However, this solution is typically only seen at BRT routes. At the same time, they find that bus bays are a little safer than kerbside bus stops.

Perceived safety
Both cyclists and passengers get a sense of insecurity about the traffic situation at bus stops. Studies from (for example) the Municipality of Aalborg show that both cyclists and passengers frequently experience unsafe situations and potential conflicts at these locations. About 80 % of responding cyclists and about 40 % of responding passengers feel unsafe when they either pass a bus stop on a bicycle, or board or exit a bus.

Campaigns and measures such as coloured surfacing on cycle tracks at bus stops can have a small but positive effect on cyclists' and passengers' perceived safety.

Passability and other effects
Bus stops on roads with cycle tracks or lanes generally reduce the passability for cyclists because they either have to give way for bus passengers, lower their speed and make sure that passengers observe their duty to give way, or have to wait behind the bus.

Establishing bus islands on sections with cycle tracks (which impose on passengers a duty to give way on boarding or exiting the bus), and establishing bus bays on sections with cycle lanes (which allow cyclists to pass a stationary bus) can reduce any negative effect on cyclists' passability.

8.3 Recommended use
The combination of bus stops and two-way cycle paths should only be established if a wide verge can be made between the cycle path and the bus stop.

It is appropriate to establish bus islands where there are cycle tracks. However, in narrow locations it may be necessary to omit bus islands and let passengers board and alight directly onto the cycle track. If a bus stop is established on a section with cycle lane, a reinforced cycle lane is recommended, or a cycle lane in front of the bus bay.

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9 Car parking alongside a cycle track or cycle lane

9.1 Description of the measure

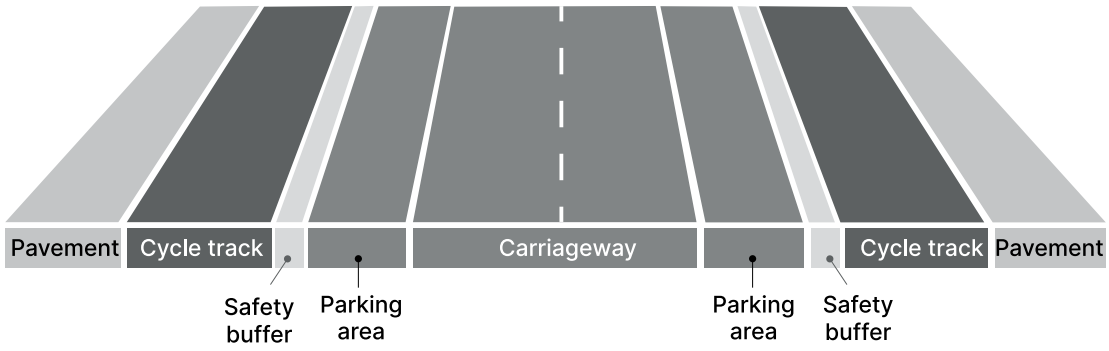
Parking alongside cycle tracks should be done between the cycle track and carriageway using:

- Longitudinal (parallel) kerbside parking with or without markings and (where possible) signs for parking.
- Longitudinal (parallel) kerbside parking in a parking bay bounded by kerbs.
- Angled or perpendicular parking, where the cars are parked at an angle or perpendicular to the cycle track.

Parking alongside cycle lanes can be established either between the cycle lane and carriageway or between the cycle lane and the pavement, though the latter is seldom seen in Denmark. Angled or perpendicular parking is not recommended. Instead, typically parking is established as:

- Longitudinal (parallel) parking in marked spaces.
- Longitudinal (parallel) parking in parking lanes.

In order to minimise the risk that opening the doors of vehicles parked at the kerbside may cause cycle accidents, a safety buffer should be established (e.g. a buffer strip) between the parking area and the cycle track or lane. This will also function as a refuge for pedestrians. The buffer strip should be at least 0.8m wide, or 1.5-2.0m if it is used by pedestrians.



9.2 Effects on road safety and perceived safety

	Effects for cyclists				
	Longitudinal (parallel) kerbside parking alongside cycle track	Angled or perpendicular parking alongside cycle track	Longitudinal (parallel) parking alongside cycle lane	Safety buffer between parking area and bicycle facility	Prohibition of parking
Safety					
Perceived safety					
Passability					

Road safety
Longitudinal car parking alongside a cycle track or lane may increase the risk of conflicts and bicycle accidents – particularly in connection with opening car doors, and pedestrians crossing the cycle track or lane to get to or from parked cars.

Angled or perpendicular parking has a limited importance in relation to cyclists on the cycle track, but gives rise to a generally high risk of accidents – for example from reversing vehicles.

Establishing a safety buffer (marked or raised) between the cycle track/lane and parking facilities can be a good yet space-consuming measure for improving cyclists' safety. A safety buffer reduces the risk of door accidents with cyclists, and at the same time offers an area for pedestrians, and for drivers accessing their cars, thus also reducing the risk of cyclist-pedestrian conflicts.

The prohibition of parking may minimise these road safety problems but relocating parking opportunities to side roads will increase traffic on side roads and thus increase the risk of accidents at junctions.

Perceived safety
Parking along cycle tracks and cycle lanes creates a sense of insecurity for cyclists – especially the risk of car doors unexpectedly opening along the track. In a survey from Austria, more than 80 % of responding cyclists reported that parallel parking along cycle tracks makes them feel unsafe. Angled or perpendicular parking alongside a cycle track precludes the risk associated with the opening of vehicle doors.

Establishing a safety buffer between the cycle track or lane and parking facilities, or increasing the width of the cycle track or lane may also reduce the cyclists' sense of insecurity. Likewise, a coloured cycle lane will probably increase car occupants' awareness of cyclists, which may also reduce cyclists' sense of insecurity.

Passability and other effects
Parking alongside and close to cycle tracks and cycle lanes may cause cyclists to lower their speed – both as a result of the physically narrowed street space and in order to be able to brake or give way due to the opening of car doors, or car occupants crossing the cycle track or lane. Establishing a safety buffer between the cycle track or lane and parking, or increasing the width of the cycle track or lane may reduce this effect.

A coloured cycle lane can clarify the use of the cycle lane and make drivers consider not parking on or too close to the cycle lane, as well as make them pay attention when opening doors and crossing the cycle lane. This may have a positive effect on cyclists' passability.

Cars being illegally parked wholly or partly on the cycle lane, reduce passability of cyclists, since the cyclists will have to give way or brake.

9.3 Recommended use

Parking alongside a cycle track and cycle lane generally creates issues for cyclists' safety (and perceived safety), and for traffic flow. If longitudinal parking is established alongside a cycle track or lane, a safety buffer should be implemented between the two. For this reason a particular street width is necessary.

Angled or perpendicular parking is not suitable for main roads or local roads with a certain volume of through traffic in the interests of safety on the road.

9.4 Further reading

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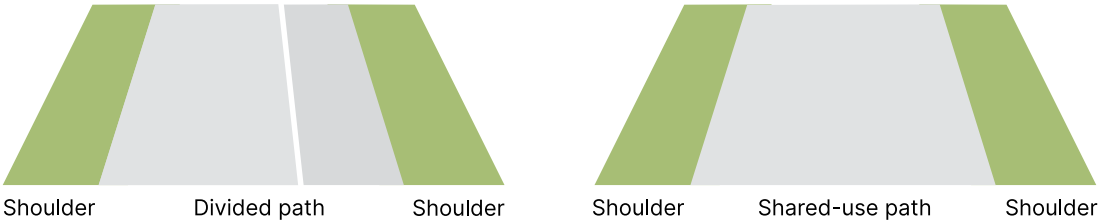
10 Divided and shared-use paths

10.1 Description of the measure

Divided and shared-use paths are for cyclists and pedestrians where the two road user groups are not physically divided. On a divided path, cyclists and pedestrians are segregated via markings or surfacing etc. On a shared-use path, cyclists and pedestrians are not segregated. Divided paths and shared-use paths can be established along roads or may be located in places such as parks, through residential areas with no vehicular roads, or riversides, and they can be both one and two-way for the cyclists.



The purpose of divided paths and shared-use paths is to improve conditions for the cyclists and pedestrians, dog walkers, wheelchair users etc that share them, either where space is too limited to provide both a cycle track and pavement or the number of pedestrians and cyclists are low.

10.2 Effects on road safety and perceived safety

	Effects for cyclists	
	Divided path	Shared-use path
Safety	😐	😐
Perceived safety	🙂	😐
Passability	🙂	☹

Road safety

The safety implications of divided paths and shared-use paths are not clear and depend on many factors. Along roads the number of accidents between cyclists and motor vehicles on some stretches may be reduced compared to roads with no bicycle facilities. Contrary to this, the measures may cause an increase in serious accidents at junctions. In particular, this applies if the cyclists' part of the shared or divided path is two-way, meaning cyclists approaching from the "wrong" side may surprise drivers at junctions that intersect with the divided or shared path.

Further, divided and shared-use paths may (compared to cycle track and pavement) increase the level of conflict between users due to the lack of physical separation. In particular, this applies to shared-use paths, where cyclists and pedestrians are mixed, and in cases of two-way paths, where there are oncoming cyclists on a relatively narrow cross section.

Perceived safety

Generally, divided paths and shared-use paths are perceived as safer than cycle lanes or roads with no cycle lanes or tracks. This is due to the fact that on these paths, cyclists are physically separated from the vehicular traffic and have a dedicated area (apart from at junctions).

Overall, divided paths provide the greatest level of perceived safety, as cyclists are separated from pedestrians, while on shared-use paths they may get into conflict with pedestrians. However, it is probably most often cyclists who may make pedestrians feel insecure, not the other way round.

Passability and other effects

Divided paths give cyclists relatively good passability as they have a dedicated area, and a path in its own layout allows for more direct routes (but also detours). The passability, though, is not as good as on a cycle track, which is physically separated from pedestrians.

The mix of cyclists and pedestrians (including dog walkers, children playing etc.) on a shared-use path will typically require low speeds to be adopted, unless there are very few pedestrians.

Depending on path width, oncoming cyclists can reduce passability on two-way divided paths or shared-use paths, especially around bends.

The design at junctions is crucial to the total passability and experience of divided paths and shared-use paths.

10.3 Recommended use

Divided paths and shared-use paths are typically only established where the number of cyclists and pedestrians is low, or where space is too limited for a dedicated cycle track or lane.

Two-way divided paths and shared-use paths in rural areas can be a good solution, where crossing roads can be avoided to reach (for example) schools, parks, playing fields etc. Two-way divided paths and shared-use paths are not suitable along roads where there are many side roads or entries and exits across the path, as drivers are not always prepared for cyclists who may seem to approach from what is perceived as the “wrong” side.

10.4 Further reading

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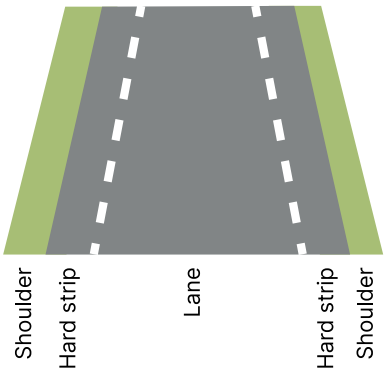
11 2-minus-1 road

11.1 Description of the measure

A “2-minus-1 road” is where a narrow road is marked as a one-lane road and has a wide hard strip down either side that can be used by vehicles to pull to one side to allow an oncoming car to pass safely, and by cyclists and pedestrians too. It is important that these hard strips are not wider than the main part of the road, so as not so be mistaken as lanes for vehicular traffic.



The intention of a 2-minus-1 road is partly to improve the conditions for cyclists and pedestrians within the existing road profile, and partly to improve road safety by reducing the speed limit (speed limits above 60km per hour is not permitted on such roads while the general speed limit outside build-up areas is 80km per hour in Denmark) and allow more space between the vehicle and any trees, poles or other fixed objects along the roadside.

11.2 Effects on road safety and perceived safety

The measure has been established in several Danish municipalities, but there are few evaluations of the effect on cyclists’ safety and perceived safety. International studies are scarce as well.

	Effects for cyclists
Safety	
Perceived safety	
Passability	

Road safety

Danish and Dutch evaluations show that 2-minus-1 roads can significantly reduce the overall number of accidents by 25 %. While less is known of their effect on reducing accidents with cyclists in particular, it seems to be a similar percentage.

Speed measurements from Denmark, Sweden, the Netherlands and Germany show that the average speed on most stretches of 2-minus-1 roads decreases by 2-5 km/h – particularly, if the 2-minus-1 road is supplemented by traffic calming measures and/or a lower speed limit. This has a positive effect on general safety and safety for cyclists on particular stretch of road.

However, several studies show that following the introduction of a 2-minus-1 road, cars pass cyclists more closely, which may have a negative effect on their safety. Furthermore, an increase in

the amount of cyclists and pedestrians who use the 2-minus-1 road may increase the risk of conflicts between these two groups of road users. Finally, it may pose a risk to safety if drivers and/or cyclists misunderstand the 2-minus 1-roads and do not use them as intended.

Perceived safety
Some studies show that cyclists feel safer on 2-minus-1 roads because they are "separated" from vehicular traffic by the dotted edge line. At the same time, the observed fall in speed levels generally has a beneficial effect on cyclists' perceived safety.

Other studies however show that cyclists do not feel safe, and that they feel pushed off the road when cars give way to each other where the road narrows or at contact situations between two cars. The reduced distance reported between cars and cycles is also something that, in general, contributes to a reduction in perceived safety.

The variations above could relate to traffic volumes – cyclists feel safe on 2-minus-1 roads with little traffic and unsafe on 2-minus-1 roads with relatively more traffic.

Passability and other effects
The importance of 2-minus-1 roads for cyclists' passability has not been evaluated in any studies and its effect is probably minimal.

On one hand, the wide hard strip may ensure good passability for cyclists compared to a narrow road with no hard strips. On the other hand, pedestrians using the hard strip, and drivers using the hard strip in contact situations, may reduce cyclists' passability. The passability will probably be lower than on dedicated cycle tracks and lanes, and will also be affected by traffic volume.

11.3 Recommended use

2-minus-1 roads can be used on narrow roads with low traffic, low speed and good visibility conditions with the following recommendations:

- Peak hour traffic should not exceed 300 vehicles/h, and annual average daily traffic should not be higher than 3,000 vehicles/24 hours.
- The speed limit must not exceed 50 km/h in urban areas and 60 km/h outside urban areas.
- There has to be sight distance corresponding to the selected speed limit in order to ensure that road users have time to give way if they face oncoming traffic.
- 2 minus 1-roads should not be established on roads with high demand for parking along the roadside.
- 2 minus 1-roads should be supplemented with traffic calming measures.

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12 Contraflow cycling permitted

12.1 Description of the measure

A one-way road is a road where the traffic is allowed in only one direction. One-way roads may entail inconvenient detours for cyclists, and in order to avoid this, contraflow cycling can be allowed. This is done with signs showing “One way” and the additional panel “Except cycles” (or similar) at the entry (see below), and the sign “motor vehicles, tractors and agricultural vehicles prohibited” at the exit.

Apart from signposting, the measure may also include a range of physical or road-marking features, such as the establishment of contraflow cycle track or lane. These should be set up using the same width as a standard cycle track or cycle lane.

12.2 Effects on road safety and perceived safety

	Effects for cyclists
Safety	☺
Perceived safety	☺
Passability	☺

Road safety

Various studies from several different countries show that the measure actually seems to improve road safety. Indeed, it appears that cycling with the traffic flow is more dangerous in one-way streets than contraflow cycling.

The reasons for increased safety vary:

- It is safer to ride towards each other (two pairs of eyes see better than one)
- Less illegal cycling on pavements
- More cyclists and fewer cars
- Cars reduce their speed
- Increased attention and consideration for other road users
- Shortcuts for cyclists
- Bicycle traffic is moved from the main road network to local roads
- Fewer accidents with parked cars

Junctions, street parking and crossing pedestrians pose a safety risk for this measure and call for attention when implementing.

Based on previous studies it is not possible to quantify the size of the effect.

Perceived safety
The measure improves cyclists' perceived safety. At the same time, it improves cyclists' satisfaction as they are seen more easily and feel prioritised. For this reason, contraflow cycling has become a measure that cycling organisations in several countries want to implement even more. Private drivers, commercial drivers and pedestrians are generally less positive about the measure.

Passability and other effects
The purpose of the measure is primarily to improve cyclists' passability, and even though the effect has not been quantified, this purpose seems to be served. This can be explained by a shorter route (short cut) and better passability due to the presence of a dedicated cyclists' area.

12.3 Recommended use

As an unambiguously good cycle measure, contraflow cycling can be used in most one-way streets where improvement of the conditions for the cyclists is desired. However, an bespoke assessment should be made of the relevant street with special focus on whether and how any junctions, on-street parking or pedestrian crossings can be accommodated in a suitable way.

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Summary

The effect of the 12 selected road engineering measures on cyclists' safety, perceived safety and passability are summarised in the following table. The effects are divided into five main categories:

- Positive effect, which is well documented
- Likely positive effect
- No/uncertain/depending effect
- Likely negative effect
- Negative effect, which is well documented

This overview shows that most variants of selected solutions typically have both positive and negative effects. There are very few solutions that have a positive effect on both road safety, perceived safety and traffic flow. The solutions, where this is the case, are: pre-green light in signal-controlled junctions; bus islands at bus stops; safety buffer between parking area and bicycle facility; and contraflow cycling permitted in one-way streets. Thus, these are solutions, which are unambiguously good cycle solutions.

Some road engineering measures have no positive effects in relation to road safety, perceived safety and traffic flow. In these cases, the measures can be improved by additional measures.

For the remaining solutions, it is necessary, prior to selecting a solution, to put road safety, perceived safety and traffic flow for cyclists into order of priority.

Finally, the overview shows that often the effects of the selected measures are "likely", but robust evidence is scarce. In particular, the effects on perceived safety and traffic flow are rarely quantified.

Measure	Safety	Perceived safety	Passability
Truncated cycle track at signal-controlled junctions			
Full-length cycle track at signal-controlled junctions			
a. next to a dedicated right-turn lane for vehicles			
b. next to a combined straight-ahead and right-turn lane for vehicles			
Cycle lane between straight-ahead and right-turn lanes			
Protected junctions			
Two-way cycle paths at junctions			
a. Signal-controlled junctions: separate control			
b. Priority T-junctions: duty to give way is imposed on the vehicle			
c. Priority T-junctions: duty to give way is imposed on the cyclist			
Cycle signals at junctions			
a. Separate control			
b. Early release			
c. Early red			
d. Right-turn arrow			
Bicycle facilities at urban roundabouts			
a. Cycle track at the roundabout			
b. Cycle lane at the roundabout			
c. Coloured markings			
d. Setback cycle path outside the roundabout			
e. No bicycle facility at the roundabout			
Bicycle facilities at bus stops			
a. Bus stops next to a cycle track (no bus island)			
b. Bus stops next to a cycle lane (no bus island)			
c. Bus island			

Measure	Safety	Perceived safety	Passability
Car parking alongside a cycle track or cycle lane			
a. Longitudinal (parallel) kerbside parking alongside cycle track			
b. Angled or perpendicular parking alongside cycle track			
c. Longitudinal (parallel) parking alongside cycle lane			
d. Safety buffer between parking area and bicycle facility			
e. Prohibition of parking			
Divided and shared-use paths			
a. Divided path			
b. Shared-use path			
2-minus-1 road			
Contraflow cycling permitted			

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