Road Technical Solutions for Cyclists

Effect on Safety and Sense of Security

Vejdirektoratet
Danish Road Directorate

Transport- og Boligministeriet

Road Technical Solutions for Cyclists
Effect on Safety and Sense of Security

Date:
June 2020

ISBN (NET):
978-87-93945-93-7

Preface and reading instruction

This booklet provides a brief summary of the effects on cyclists' safety, sense of security and passability for 10 selected road technical solutions divided into 23 variants of solution. For other road user groups, the effects are not described.

The summary is based on a comprehensive review of literature, which was carried out in 2020 on the basis of Danish and foreign recommendations, experience and evaluations from the past 20 years or so. The effects for cyclists are summarised with the symbols in the overview below. The effects on accidents cover accidents involving personal injury and material damage.

The purpose of the booklet is to help road and traffic planners and others to choose the good solutions in the work of getting more people to choose the bicycle rather than the car, along with improving the safety for cyclists. More information about the detailed design of the various solutions is to be found in the road standards.

Danish Road Directorate, June 2020

The safety effect related to road safety, sense of security etc.

	**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 situation).
	**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.

Contents

Introduction

In Denmark, we want to improve cycling. In order to do that, as planners it is important to considerate road safety and the sense of security for cyclists in the traffic technical measure.

Road safety is the objective quantitative knowledge/data we have on how many fatalities and injured people have occurred on a given location and at various road technical solutions across locations.

On the contrary, the sense of security for cyclists is about the cyclists' own subjective and qualitative sense of their safety when moving in traffic, and hence are users of the various road technical solutions. Thus, road users, to a wide extent, base their perception of security in the traffic on what they themselves experience intuitively and emotionally.

The experience of security may affect the the road users' choice of means of transport and routes. A high degree of sense of insecurity makes the cyclist less prone, in the future, to choose the actual route again, and perhaps to cycle altogether.

It is assumed that vulnerable road users who, in general, already feel exposed in the traffic, such as e.g. elderly cyclists, easier feel unsafe.

As traffic planner, one might be led to believe that road safety and sense of security go hand in hand: That when you choose the safest solution in terms of road safety, and communicate this, the cyclists will also find it safe to travel in. But this is far from being the case.

Often, when wanting to improve cycling opportunities, a balancing of road safety and experienced sense of security has to be carried out concerning the road technical solutions to be selected.

This booklet provides an overview of 10 different road technical solutions for cyclists in relation to road safety for the cyclists and the cyclists' subjective sense of security, respectively. Where possible, the cyclists' passability is also stated.

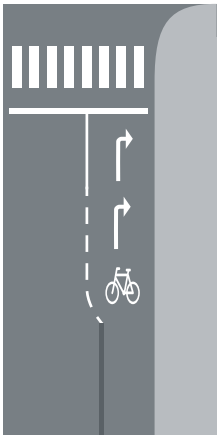
The booklet is a collection of available evaluations and describes, at a general level, the 10 road technical solutions. When shaping a specific system, it will always be necessary to perform an assessment of the actual conditions.

1 Truncated cycle lane in signal-controlled intersections

1.1 The measure

A truncated cycle track is a cycle track (or cycle lane) which terminates at the start of the right-turn lane, typically, 15-25m before the intersection. Cyclists and mopeds must, regardless of the movements in the intersection, continue into the right-turn lane and merge with the right-turning vehicular traffic. The lane is to be marked with right-turn arrows and cycle symbol.

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



1.2 The effects

	Effects for the cyclists
Road Safety	
Sense of security	
Passability	

Road Safety

Truncated cycle lanes are a good step concerning road safety for cyclists in signal-controlled intersections. The most recent and excellent Danish study has found that reconstruction from regular terminated cycle lane to truncated cycle path reduces the number of bicycle and moped accidents with about 60 % in the actual intersection leg, while reconstruction from no bicycle facilities to truncated cycle path reduces the number of bicycle and moped accidents with about 50 %. The effects are stated for accidents with right-turning cars, accidents with left-turning cars from opposite side and side-swipe collisions in the approach to the intersection

Before-situation	After-situation	Effects on cycle and moped accidents *
No measures for cyclists	Truncated cycle lane	The number of accidents is reduced with 50 %
Regular terminated cycle lane along a combined straight ahead and right-turn lane	Truncated cycle lane	The number of accidents is reduced with 60 %
Regular terminated cycle lane next to a separate right-turn lane	Truncated cycle lane	The number of accidents is reduced with 60 %

** The effect has been estimated for accidents with right-turning cars, accidents with left-turning cars from opposite side and accidents caused by congestion in actual intersection legs (accident main situation 1, 3 and 4).*

Sense of security
Generally, relative to regular terminated cycle tracks (and lanes), truncated cycle tracks increase the cyclists experienced sense of security, while the effect will be minimal, if in the before-situation no bicycle facilities were available. Increased sense of security can be explained by the cyclists being mixed with the vehicular traffic. In particular, this may be challenging for insecure cyclists such as children and elderly people.

Traffic flow and other effects
Compared to regular terminated cycle tracks (and lanes), truncated cycle tracks entail a potential reduction of the traffic flow for cyclists, since they do not have a separate area and thereby, in some cases, shall give way to the cars in the merging situation. At the same time, they risk that the vehicles or any queue of vehicles should bar the road.

1.3 Area of use

Truncated cycle tracks are to be preferred from a road safety point of view. The measure may entail a reduced sense of security compared to regular terminated cycle lanes – this applies in particular to insecure cyclists. The measure is particularly relevant if:

- There are a lot of mopeds, e-bikes, speed pedelecs or cycle commuters at high speed.
- It is going downhill.
- Space is limited.
- There is no need for separate control of the cyclists.

1.4 The most important sources

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

Djupdræt, U. & Wass-Danielsen, M. (2017). Fremtidens krydsdesign - sikkerhed og tryghed ved fremførte og afkortede cykelstier, Trafikdage, AAU.

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

Jensen, M. L. & Sørensen, M. W. J. (2020). Trafiksikkerhed ved afkortede og fremførte cykelstier i signalregulerede kryds – en før-efter ulykkesevaluering, Via Trafik.

Jensen, S. U. (2006). Effekter af cykelstier og cykelbaner, Trafitec.

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

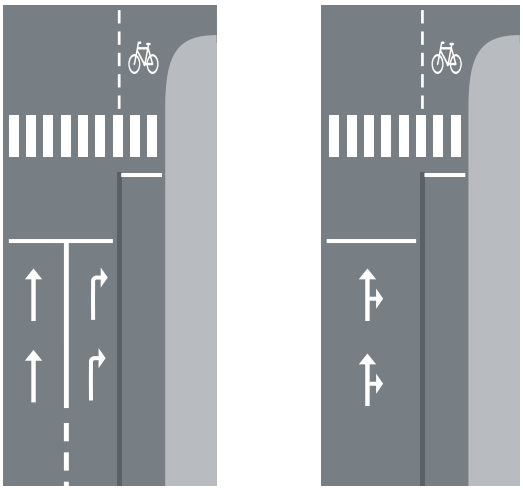
2 Regular terminated cycle lane in signal- controlled intersections

2.1 The measure

A regular terminated cycle track is a traditional cycle track (or cycle lane), which has been established right through to the intersection on the right side of the lanes for the vehicular traffic. Often, a regular terminated cycle lane is combined with an advanced stop line of 5m for cyclists. The measure is found in two main variants:

- Regular terminated cycle lane next to a separate right-turn lane for vehicles.
- Regular terminated cycle lane next to a combined straight ahead and right-turn lane for vehicles.

The intention of a regular terminated cycle lane is to ensure good passability and a good sense of security for the cyclists by the fact that they have their own track through to the intersection. At the same time, the safety is being handled by i.a. having advanced stop line for cyclists and possibly cycle signal, which makes it easier for right-turning vehicles and left-turning vehicles (from the opposite side) to see the cyclists going straight ahead.



2.2 The effects

Effects for the cyclists		
	Regular terminated cycle lane next to a separate right-turn lane for vehicles	Regular terminated cycle lane next to a combined straight ahead and right-turn lane for vehicles
Road safety	😐	☹
Sense of security	☺	☺
Passability	☺	☺

Road safety
The effect concerning road safety depends on whether the measure is located next to a separate right-turn lane for cars or next to a combined straight ahead and right-turn lane, and with which other solutions comparison is done.

A regular terminated cycle lane next to a separate right-turn lane is significantly safer than a regular terminated cycle lane next to a combined straight ahead and right-turn lane. A reconstruction from combined straight ahead and right-turn lane to separate right-turn lane thus reduces the number of bicycle and moped accidents with about 50 % in the actual intersection leg.

If intersections without cycle facilities are reconstructed to include regular terminated cycle lane with separate right-turn lane, it seems to have some effect concerning road safety. The establishment of regular terminated cycle lane with combined straight ahead and right-turn lane will in this case increase the number of bicycle and moped accidents with about 130 %.

Older studies have found that there is no noteworthy difference on the safety level in intersection legs with regular terminated cycle lane, while recent studies find that the establishment of a truncated cycle path (both variants) in an intersection leg, where previously a truncated cycle lane existed, will give a significant increase in the number of cycle and moped accidents of 200-250 %.

Before-situation	After-situation	Effects on cycle and moped accidents *
No measures for cyclists	Regular terminated cycle lane next to a separate right-turn lane	No change
No measures for cyclists	Regular terminated cycle lane along a combined straight ahead and right-turn lane	The number of accidents is increased with 130 %
Truncated cycle track	Regular terminated cycle lane next to a separate right-turn lane	The number of accidents is increased with 200 %
Truncated cycle track	Regular terminated cycle lane along a combined straight ahead and right-turn lane	The number of accidents is increased with 250 %
Regular terminated cycle lane along a combined straight ahead and right-turn lane	Regular terminated cycle lane with separate right-turn lane	The number of accidents is reduced with 50 %

** The effect has been estimated for accidents with right-turning cars, accidents with left-turning cars from opposite side and accidents caused by congestion in actual intersection legs (accident main situation 1, 3 and 4).*

Sense of security
A regular terminated cycle lane improves the cyclists' experienced sense of security compared to a truncated cycle track and an intersection leg without any cycle facilities. This is due to the cyclists getting their own, dedicated area, which is physically separated from carriageway and pavement.

Passability and other effects
The measure also improves the cyclists' traffic flow compared to truncated cycle track and intersection leg without any cycle facilities, since the cyclists get their own dedicated area, which is physically separated from the lane and the pavement.

2.3 Area of use

The solution of a regular terminated cycle lane next to a combined straight ahead and right-turn lane is, from a safety point of view, not the best solution for the cyclists. Regular terminated cycle lane next to a separate right-turn lane is better from a safety point of view, and may be used in an intersection leg, where sense of security and/or traffic flow is particularly important to the cyclists. Regular terminated cycle lanes entail more accidents, and they are more space consuming than truncated cycle lanes and less suitable when the cyclists travel at high speed.

2.4 The most important sources

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

Djupdræt, U. & Wass-Danielsen, M. (2017). Fremtidens krydsdesign - Sikkerhed og tryghed ved fremførte og afkortede cykelstier, Trafikdage, AAU.

Jensen, M. L. & Sørensen, M. W. J. (2020). Trafiksikkerhed ved afkortede og fremførte cykelstier i signalregulerede kryds – en før-efter ulykkesevaluering, Via Trafik.

Jensen, S. U. (2006). Effekter af cykelstier og cykelbaner, Trafitec.

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

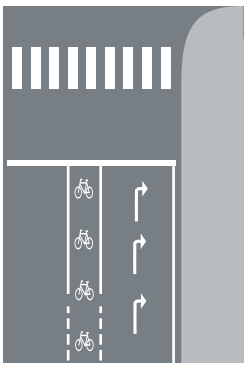
3 Cycle lane between straight ahead and right-turn lane

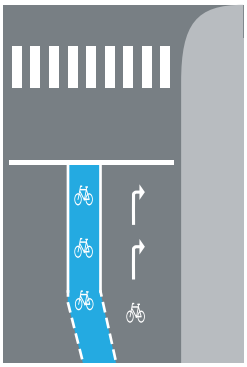
3.1 The measure

The cycle track/lane is carried forward as a marked cycle lane between the straight ahead and the right-turn lane for the vehicular traffic, i.e. to the left of the right-turn lane. The cycle lane is to be marked with cycle symbols, and it can also be marked as blue space for cyclists, while the right-turn lane is to be marked with turn arrows and possibly also with cycle symbols.

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

The idea of the measure is to replace the hazardous conflicts between right-turning motor vehicles and straight ahead cyclists with less hazardous merge situations before the actual intersection. At the same time, the straight ahead cyclists are becoming 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 The effects

	Effects for the cyclists
Road safety	
Sense of security	
Passability	

Road Safety
The measure is recommended and is used as traffic safety measurement in a lot of countries. However, it is only a few studies from Denmark and Norway that have looked into the safety effect. These studies provide no unambiguous conclusions, but it does not seem like the measure entails more bicycle accidents. Other studies, which indirectly have investigated the effect, find that the measure probably has a positive safety effect.

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

On the basis of the studies it is not possible to quantify the size of the effect.

Sense of security
It is inconclusive whether the measure has a positive or negative effect on the cyclists' experienced sense of security. The effect depends on the before-situation. If the before-situation is that the cyclists are moving to the right roadside on a regular terminated cycle track/lane, the measure can increase the uncertainty. Both the merging situation before the intersection and the fact of there being lorries and buses on both sides, which might make them feel unsafe.

If, on the other hand, the cyclists already travel in the middle of the lane and/or in an intersection leg with truncated cycle track, the marked cycle lane will make them feel safe. This is due to the fact that part of the carriageway area, with this, is reserved to the cyclists.

Passability and other effects
The measure probably improves the cyclists' passability. Firstly, the measure provides the 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 this occurs), which improves the passability for the cyclists.

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

3.3 Area of use

The measure can solely be used in signal-controlled intersections, where there is a separate right-turn lane, and, typically, it will be established where a truncated cycle lane exists. It should be ensured that the merge situation will happen at a low speed, thus making it most suitable for intersections with speed limits not exceeding 50km/h.

3.4 The most important sources

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 Two-way cycle paths in intersections

4.1 The measure

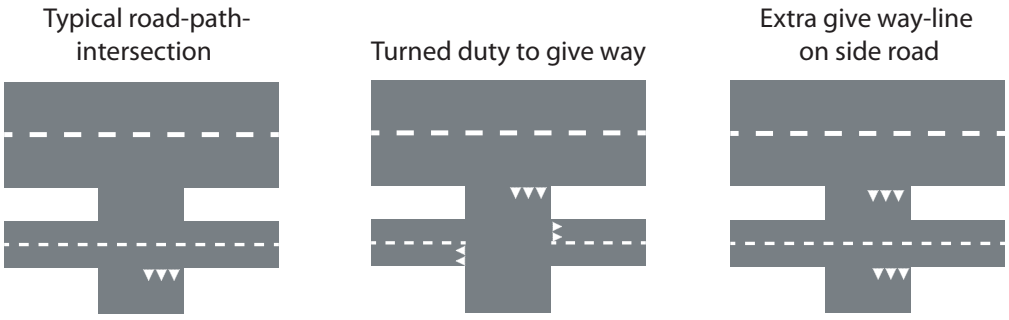
Two-way cycle paths through intersections pose a special challenge and, as a result, they should, if possible, be constructed as ***a grade separated crossing***. Where this is not possible, crossing of traffic routes in level should be carried out as signal control or as a T-junction controlled by duty to give way. The circular on the establishment of two-way cycle lanes along roads describes how to establish the cycle lanes.

In ***signal-controlled intersections*** two-way cycle paths should be handled by cycle-only phases to avoid conflicts of duty to give way concerning right or left turning vehicles. A two-way cycle path should always be established right through to the intersection and have a maximum width of 3m at the intersection. There must be at least 0.5-1m between path and lane.

In ***T-junctions controlled by duty to give way*** 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 path user
- Give way lines on the secondary road before the cycle path and before the primary road

The two-way cycle path should run minimum 6m away from the primary road. Clear indication of the conditions for the duty to give way, and the duty to give way for the cyclists can be emphasised by the establishment of traffic calming measures on the lane such as a raised surface.



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

4.2 The effects

Effects for the cyclists			
	Separately controlled signal control	T-junction controlled by duty to give way, where drivers have the duty to give way	T-junction controlled by duty to give way, where cyclists have the duty to give way
Road safety			
Sense of security			
Passability			

Road Safety
Concerning road safety, generally, two-way cycle paths are problematic in intersections. This is especially due to the fact that the drivers (both crossing, right-turning and left-turning from the opposite side) do not always consider cyclists approaching from the “wrong” side. Right-turn motorists also find it difficult to discover cyclists coming from behind in the same direction because they are too far from the lane.

Signal-controlled intersections with two-way cycle path should be separately controlled, since this separates traffic of vehicles and cycles in time and thus gives control, free of conflict (provided that red signal is observed).

Two-way cycle paths and junctions controlled by duty to give way are a worse combination, and for this reason the measure should only be implemented in T-junctions. Studies show that there is a high risk of accident, especially for cyclists approaching from the “wrong” side.

In order to improve the road safety in T-junctions controlled by duty to give way, moving the duty to give way to the path users or establishing extra give-way line on the side road may be very effective measures. Further or alternatively, the raised surfaces, space for cycles as well as marking and signposting can contribute to increase the safety.

Sense of security
The effects on experienced sense of security by separately regulating the two-way cycle paths in signalled intersections have not been investigated. However, with great probability the measure is estimated to have a positive effect due to the cyclists’ separation, regarding time, from the vehicular traffic in intersections of an often complicated kind.

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

Passability and other effects
Typically, separate control in a signal intersection will reduce the total capacity of the intersection, and any limited green time for the cyclists will cause increased delay and thus poorer accessibility for the cyclists.

The imposing on the cyclists of the duty to give way, and possible adding of traffic-calming measures in T-junctions controlled by duty to give way, will reduce the passability of the cyclists.

4.3 Area of use

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

Two-way cycle paths in F-junctions should be signal-controlled, while in T-junctions they can also be controlled by duty to give way (roundabouts are not treated here). In intersections controlled by duty to give way, the path users should have the duty to give way imposed on them from a point of view of road safety. The solution, in which the vehicular traffic has the duty to give way, is only recommended where there is a limited side road traffic, or where the passability for path users needs prioritising.

4.4 The most important sources

Høye, A. (2017). Trafiksikkerhet for syklister. TØI.

Høye, A., Sørensen, M. W. J. & de Jong, T. (2015). Separate sykkelanlegg i by. TØI.

Buch, T. S. & Jensen, S. U. (2013). Trafiksikkerhed i kryds med dobbeltrettede cykelstier. Trafitec.

Ministeriet for Offentlige arbejder (1984). Cirkulære om etablering af dobbeltrettede cykelstier langs vej, CIR NR 95 AF 06/07/1984.

5 Cycle signals in intersections

5.1 The measure

Cycle signals are used for the control of path users in approaches with regular terminated cycle track or lane in signal-controlled intersections. The measure is found in a range of variants. The most frequent are:

- **Separate control:** Separate signal phase for cyclists. The intention is to obtain a control for cyclists and vehicular traffic free of conflict.
- **Before-green:** Cyclists waiting at the stop line, will be released by green signal a few seconds before the vehicular traffic. The intention being that the cyclists are given the opportunity to proceed earlier and be in the middle of the intersection, when the right-turning vehicular traffic is being completed.
- **Before-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 3 section cyclist signal and 1 section right-turn cyclist signal. The intention is that vehicular and cycle traffic can turn to the right at the same time.

5.2 The effects

Effects for the cyclists				
	Separate control	Before-green	Before-red	Right-turn arrow
Road safety				
Sense of security				
Passability				

Road Safety

Control, free of conflict, of cycle and vehicular traffic in the shape of separate control in signal-controlled intersections provides the best solution from a safety point of view (together with grade separated crossing) This way, signal-controlled right turns reduce the number of right-turn accidents with about 75 % compared to signal-controlled intersections without a right-turn phase.

Before-situation	After-situation	Effects on cycle and moped accidents *
Signal-controlled intersection without separately controlled right-turn	Signal-controlled intersection with separately controlled right-turn	The number of bicycle and moped accidents are reduced with about 75 %

** The effects concern accidents with right-turning cars in actual intersection legs (accident main situation 3).*

For the cyclists before-green means that cyclists after red signal will move into the intersection faster and thus become more visible to right-turning cars, buses and lorries. This contributes, with great probability, to reduce the number of right-turn accidents.

Before-red for cyclists may contribute to prevent right-turn accidents, as this gives right-turning vehicular traffic better time to turn right without getting into conflict with cyclists going ahead. However, behavioural studies show that cyclists have less respect for cycle signals that standard main signals. The measure entails that cyclists, to a higher degree, have time to pass the junction, before crossing road users from the side roads get green signal, which improves the safety.

Sense of security
The effects of cycle signals in relation to experienced sense of security have not been investigated. However, it is estimated that separate control, with great probability, has a positive effect as a result of the cyclists' time separation from the vehicular traffic.

Before-green increases the cyclists' visibility and thus the drivers' attention to these, which probably may increase the cyclists' sense of security a bit.

Before-red and right-turn arrow probably have no or only limited significance.

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

For cyclists, before-green and before-red might entail a minute either improvement or reduction of the passability for the cyclists 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 the vehicular traffic.

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

5.3 Area of use

Cycle signals may be used in signal-controlled intersections with regular terminated cycle track or cycle lane. To a notable degree, separate control, but also before-green and right-turn arrow, may be applied in intersections, where the prioritising of cyclists is requested, and/or where – due to concerns on road safety – there is a need for a time separation of the cyclists and vehicular traffic.

5.4 The most important sources

Buch, T. S. (2015). Højresvingskonflikter i signalregulerede kryds – Undersøgelse af konfliktende adfærd. Trafitec.

Høye m.fl. (2020). Trafikksikkerhetshåndboken, TØI, https://tsh.toi.no/.

Jensen, M. L., m.fl. (2018). Fastlæggelse af sikkerhedstider i trafiksignalanlæg. Via Trafik.

Jensen, S. U. & Buch, T. S. (2017). Trafiksikkerhedsmæssige effekter af signalanlæg – Litteraturstudie og før-efter uheldsevaluering af svingfaser. Trafitec.

6 Cycle infrastructure at bus stops

6.1 The measure

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

- **Bus stop with a wide island** between the cycle track and the carriageway, where waiting passengers can stay and where passengers from the bus have an exit area.
- **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 waiting/exit area.
- **Bus stop on pavement,** where waiting passengers can stay on the pavement, and where descending passengers must exit directly onto the cycle track.

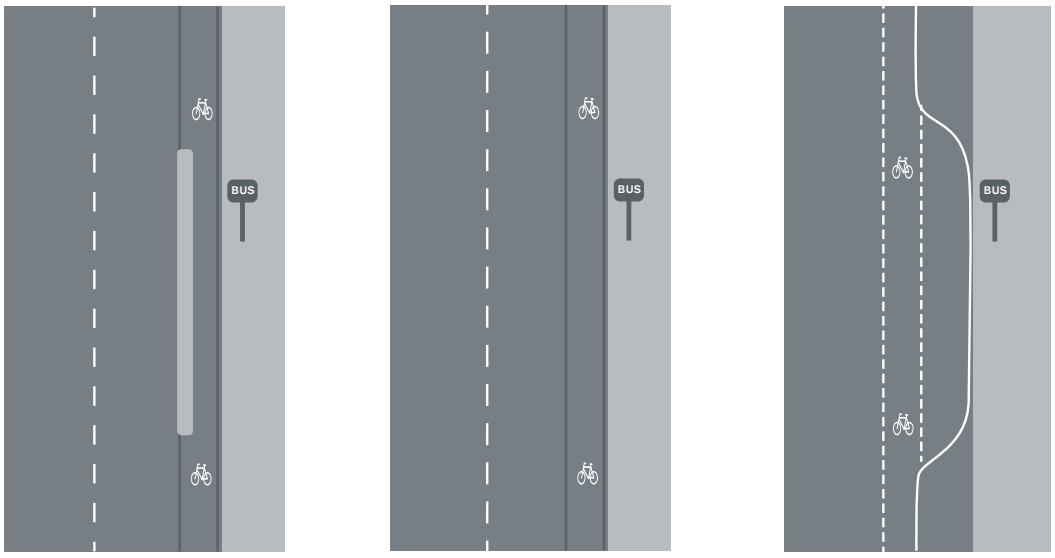
On roads with **cycle lanes**, the following solutions are typically established in connection with bus stops:

- **Reinforced cycle lane,** where the cycle lane is upgraded to a cycle track, and the above cycle track solutions are to be used.
- **Bus stop on pavement,** where the bus drives in and stands on the cycle lane, so that cyclists will have 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 **without cycle facilities**, the bus stop is typically established at the kerbside, where cyclists will 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 entry and exit as well as navigate without getting involved in conflicts with the cyclists.



6.2 The effects

Effects for the cyclists			
	Bus stop at cycle track	Bus stop at cycle lane	Bus island
Road safety			
Sense of security			
Passability			

Road safety
Bus stops on roads with cycle tracks/lanes pose a challenge concerning road safety, especially with regard to conflicts and accidents between passengers and cyclists. The risk of accidents is particularly high at two-way cycle paths.

Generally, bus islands reduce the risk of accidents between passengers and cyclists.

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

Foreign studies find that, generally, the least number of 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 bit safer than bus stops at the kerbside.

Sense of security
At bus stops, both cyclists and passengers get a sense of insecurity about the traffic situation, and studies from i.a. the Municipality of Aalborg show that both cyclists and passengers frequently experience unsafe situations and potential conflicts at the bus stops. Of the responding cyclists about 80 %, and of the responding passengers about 40 % feel unsafe, when they either pass a bus stop on a cycle or enter or exit a bus.

Campaigns and measures e.g. as coloured surfacing on the cycle tracks at the bus stops can have a small, but positive effect on the cyclists' and passengers' sense of security.

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

The establishment of bus islands on sections with cycle tracks, which impose a duty to give way on passengers entering or exiting, and the establishment of bus bays on sections with cycle lanes, which allow for passing a waiting bus, can reduce the negative effect for the passability.

6.3 Area of use

The combination of bus stops and two-way cycle paths should only be established, if a wide verge can be made between cycle path and stopping place.

Where there are cycle paths, it is fitting to establish bus islands. However, in places with narrow space, it may be necessary to leave out bus islands and let passengers board and alight directly onto the cycle path.

If a stopping place is established on a section with cycle lane, “reinforced cycle lane” is recommended or cycle lane in front of the bus bay.

6.4 The most important sources

Baier, R. m.fl. (2007). Potenziale zur Verringerung des Unfallgeschehens an Haltestellen des ÖPNV/ÖPSV.

Berge, S. H., Hagen, O. H. & Phillips, R. O. (2019). Effekt av holdeplasser på trafiksikkerhet og fremkommelighet. TØI.

Høye m.fl. (2020). Trafikksikkerhetshåndboken (Holdeplasser for buss og trikk), TØI.

Jensen, S. U. (2006). Effekter af cykelstier og cykelbaner, Trafitec.

Nordjyllands Trafikselskab m.fl. (2018). Undgå KLASK! - Tryghed i mødet med bussen.

Vejdirektoratet (2016). Kollektiv bustrafik og BRT.

7 Car parking alongside cycle track and cycle lane

7.1 The measure

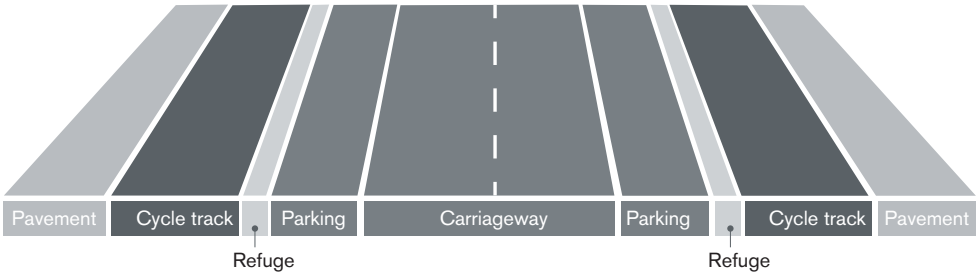
Parking ***alongside cycle tracks*** should be established between cycle track and carriageway, and can be established as:

- **Longitudinal (parallel) kerbside parking** with or without markings and 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 both between cycle lane and carriageway and between cycle lane and 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 of vehicle doors at kerbside parking may cause cycle accidents, the point of conflict between exiting car occupants and cyclists should be made visible by establishing a safety buffer (e.g. a buffer strip) between the parking area and the cycle track/lane. This will also function as a refuge for the pedestrians. The buffer strip should be at least 0.8m wide and 1.5-2.0m, if it is used by pedestrians walking alongside.



7.2 The effects

Effects for the cyclists					
	Parallel parking alongside cycle track	Angled or perpendicular parking alongside cycle track	Parallel parking along cycle lane	Safety zone	No parking
Road safety					
Sense of security					
Passability					

Road Safety
Kerbside parking of cars alongside cycle track/lane may increase the risk of conflicts and bicycle accidents – particularly in connection with open car doors and pedestrians crossing the cycle track/lane to/from the parked cars.

Angled or perpendicular parking has a limited significance in relation to cyclists on the cycle track, but gives rise to a generally high risk of accidents due to i.a. reversing vehicles.

The establishment of safety zones (marked or buffer) between cycle track/lane and parking can be a good, but space-consuming measure for improving the cyclists' safety. A safety zone reduces the risk of door accidents with cyclists, and, at the same time, it offers a standing area for pedestrians and for passengers to and from cars, thus also reducing the risk of cyclist-pedestrian conflicts.

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

Sense of security
Parking along cycle track and cycle lane, and especially the opening of car doors, create a sense of insecurity for the cyclists. In a survey from Austria, e.g. over 80 % of the responding cyclists replied that parallel parking along the cycle track makes them feel unsafe. Angled or perpendicular parking alongside a cycle track does not provide the same issues with opening of vehicle doors.

The establishment of a safety zone between cycle track/lane and parking or increased width of cycle track/lane may reduce the cyclists' sense of insecurity. At the same time, a coloured cycle lane can probably increase the attention of the car occupants, which may also reduce the sense of insecurity.

Passability and other effects
Parking along with and close to cycle tracks and cycle lanes may affect the cyclists to lower the speed – both as a result of the physically narrowed street space and in order to be able to brake/yield due to any opening of car doors or due to car occupants crossing the cycle track/lane.

The establishment of a safety zone between cycle track/lane and parking or increased width of cycle track/lane may reduce this moderating effect on passability.

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

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

7.3 Area of use

Parking alongside cycle track and cycle lane generally creates issues for cyclists, both regarding safety, experienced sense of security and traffic flow. If kerbside parking is established alongside cycle path/lane, a safety buffer should be made between parking and cycle infrastructure. This is why a certain width of the street space is needed.

Angled or perpendicular parking is not suitable for main roads or local roads with a certain volume of through traffic, out of regard for the safety on the carriageway.

7.4 The most important sources

Andersen, T. (2019). Idékatalog for cykeltrafik. Cycling Embassy of Denmark.

Høye, A. (2017). Trafiksikkerhet for syklister. TØI.

Høye, A., Sørensen, M. W. J. & de Jong, T. (2015). Separate sykkelanlegg i by. TØI .

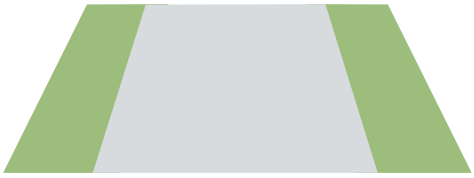
Jensen, S. U., Rosenkilde, C. & Jensen, N. (2007). Sikkerhed og tryghed på cykelstier i København. Dansk Vejtidsskrift.

Graser, A. m.fl. (2014). Safety of urban cycling: A study on perceived and actual dangers. Transport Research Arena (TRA), Paris.

8 Divided path and shared use path

8.1 The measure

Divided paths and shared use paths are reserved 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, surfacing or otherwise. On a shared use path, cyclists and pedestrians are not segregated, and thus, they must share the area of path. Divided paths and shared use paths can be established along roads or in their own layout, 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 cyclists and pedestrians on stretches without infrastructure for vulnerable road users by ensuring that they get areas/routes of their own, separated from vehicular traffic. Typically, the measures are constructed as paths in their own layout and are used on roads with few cyclists and pedestrians and with limited space, and thus being difficult to construct cycle track and pavement.

8.2 The effects

Effects for the cyclists		
	Divided pathi	Shared use path
Road safety	😐	😐
Sense of security	🙂	😐
Passability	🙂	☹

Road safety

The effect of divided paths and shared use paths, regarding safety, is ambiguous and depends on a lot of parameters. The number of accidents between cyclists and motor vehicles on some stretches may be reduced compared to mixed traffic. Contrary to this, the measures may entail an increase in serious accidents at junctions. In particular, this applies if the paths are two-way, where it might surprise the drivers that cyclists are approaching from the “wrong” side.

Further, the paths may, compared to cycle track and pavement, increase the level of conflict internally among the vulnerable road 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.

Sense of security
Generally, divided paths and shared use paths are experienced as safer than cycle lanes or roads without cycle facilities. This is due to the fact that here the cyclists are physically separated from the vehicular traffic and have a dedicated circulation area (apart from at junctions).

Overall, divided paths provide the greatest experienced sense of security, as the cyclists here are also separated from pedestrians, while on shared use paths they may get into conflict with pedestrians. However, it is particularly the cyclists who may make the pedestrians feel insecure, not the other way round.

Passability and other effects
Divided paths provide cyclists with relatively good passability, as they have their own area, and a path in its own layout gives the opportunity for some more direct routes (but also detours). The passability, though, is not as good as on a cycle track, which is physically separated from pedestrians.

Divided paths also gives the opportunity for the establishment of more direct routes, but a mixture of cyclists and pedestrians (including dog walkers, children playing etc.) will typically give a low speed level, unless there are very few pedestrians.

Depending on path width, oncoming cyclists can have a reducing effect on passability on two-way divided paths or shared use paths, especially in curves.

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

8.3 Area of use

Divided paths and shared use paths are typically only established, if the number of cyclists and pedestrians is small, or where space is limited, making it impossible to establish both pavement and cycle track/lane.

Two-way cycle paths in rural areas can be a good solution, in case it means that crossing(s) of road can be avoided, e.g. in connection with schools, playing fields and the like.

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

8.4 The most important sources

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

Høye, A. (2017). Trafiksikkerhet for syklister. TØI.

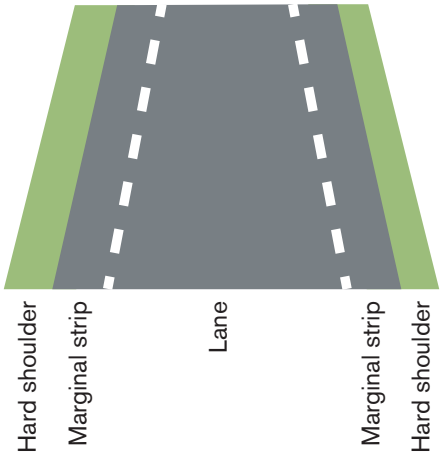
Høye, A. m.fl. (2020). Trafikksikkerhetshåndboken, TØI, https://tsh.toi.no/.

Jensen, S. & Johannessen, K. (2006). Svendborg sikker by, Dansk Vejtidsskrift.

9 2 minus-1 road

9.1 The measure

A 2 minus 1-road is a road which visually only has a single lane, but which is two-way and is used by road users in both directions. It has broad marginal strips, is marked with broken/dotted edge lines in both sides of the road, which are to be used as give way area, when two oncoming cars meet. Also, the marginal strips must be used by cyclists and pedestrians.



It is important that marginal strips are not too wide, so as not to be mistaken for lanes for the vehicular traffic.

The intention with 2 minus 1-roads is partly to improve the conditions for cyclists and pedestrians within the existing road profile, and partly to improve the road safety by reducing the speed limit and increase the distance between lane and fixed objects along the road.

9.2 The effects

Even though the measure has been established in many Danish municipalities, only few studies exists which have investigated the effect for cyclists in Denmark or other countries.

	Effects for the cyclists
Road Safety	
Sense of security	
Passability	

Road Safety

Danish and Dutch evaluation studies show that the establishment of 2 minus 1-roads entails a significant reduction of about 25 % in the total amount of accidents. The effect on accidents with cyclists has, to a lesser extent, been investigated, but it seems to be of the same order of magnitude.

From both Denmark, Sweden, the Netherlands and Germany, speed measurements show that the average speed on most of the stretches typically decreases with 2-5 km/h – particularly, if the 2 minus 1-road is supplemented with traffic calming measures and/or reduced speed limit. This has a positive effect in relation to both general safety and safety for cyclists on the section.

However, several studies show that cars and cyclists, following a reconstruction to 2 minus 1-road, pass each other at a shorter distance between them than prior to the reconstruction, which may have a negative effect on the safety. Furthermore, an increase in the amount of cyclists and pedestrians, who use the marginal strip, 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 travel on the them as designed.

Sense of security
Some studies show that cyclists feel safer on 2 minus 1-roads after being "separated" from the vehicular traffic with the dotted edge line. At the same time, the observed reduction of speed, generally, has a beneficial effect on the cyclists' sense of security.

Other studies show that the cyclists do not feel safe, and that they experience that they are being pushed off the road, when cars give way to each other at road narrowings or at contact situations between two cars. The shorter distance reported between cars and cycles is also something which, in general, contributes to a reduced experienced sense of security.

The difference in effect may relate to differences in the traffic volumes entailing that the 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 significance of the measure for the passability for cyclists has not been evaluated in any studies. Probably, the effect is minimal.

On the one hand, the broad marginal strip may ensure good passability for cyclists compared to a traditional cross section of a narrow road.

On the other hand, the pedestrians, who walk on the marginal strip, and the drivers' use of the marginal strip in contact situations, may reduce the passability. The passability will probably be lower than on dedicated systems for cyclists, such as e.g. cycle tracks.

The difference in the effect on traffic flow may, as with experienced sense of security, be explained by whether there is little or lot of vehicular traffic.

9.3 Area of use

2 minus 1-roads can be used on narrow roads with low traffic, low speed and good visibility conditions. Actually, the following area of use is recommended:

- Peak hour traffic should not exceed 300 vehicles/h, and AADT (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 of 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 great need for parking along the roadside.
- 2 minus 1-roads should be supplemented with traffic calming measures.

9.4 The most important sources

COWI (2015). 2 minus 1 veje - erfaringsopsamling. Vejdirektoratet.

Lund, B. I C. (2015). Trafiksikkerhedsanalyse af '2-1' veje. Trafitec.

Erke, A. & Sørensen, M. (2008). Veger med inntrukken kantlinje utenfor tettbygd strøk: Tiltak for syklister og gående? TØI.

10 Contraflow cycling permitted

10.1 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" (E 19) and the additional panel “Except cycles" (U 5) or similar at the entry, and the sign ”Motor vehicles, big mopeds, tractors and agricultural vehicles prohibited” (C 22,1) at the exit.

Apart from signposting, the measure may also include a range of physical or marking measures, such as the establishment of contraflow cycle track or lane. These should be established with a width similar to the other paths.

10.2 The effects

	Effects for the cyclists
Road safety	☺
Sense of security	☺
Passability	☺

Road safety
Various studies from several different countries show that the measure altogether does not entail problems concerning road safety, but on the contrary, that the measure improves the road safety. At the same time, it seems that cycling in the direction of traffic is more dangerous in one-way streets than contra-flow cycling.

The explanations of increased safety are numerous:

- It is safer to ride towards each other (four eyes see better than two)
- There will be less illegal cycling on pavements
- There will be more cyclists and less cars
- The speed limit of cars will be reduced
- There will be increased attention and consideration
- There will be shorter cycle rides
- There will be a transfer of the bicycle traffic from the main road network to the local roads
- There will be fewer accidents with parked cars.

However, intersection, street parking and crossing pedestrians pose an issue concerning road safety, and this is why this is something that should be paid special attention to when actually shaping the measure.

On the basis of the studies it is not possible to quantify the size of the effect.

Sense of security
The measure improves cyclists' sense of security concurrently with it giving a significant improvement of the satisfaction, since the cyclists to a higher degree will be seen and feel prioritised. This is why, in several countries, it has become a measure that cycling organisations want to see more widespread. 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 the passability of cyclists. Even though the effect has not been quantified, this purpose seems to be served. This in particular can be explained by a shorter route (short cut) and a better passability by cycling on the carriageway than by cycling illegally on the pavement.

10.3 Area of use

This being an unambiguously good cycle measure, it can be used in most one-way streets, where improvement of the conditions for the cyclists is desired. However, an actual assessment should be made of the relevant street with special focus on whether and how junction, on-street parking and pedestrian crossing can be designed in a suitable way.

10.4 The most important sources

Alrutz, D. m.fl. (2002). Verkehrssicherheit in Einbahnstrassen mit gegengerichtetem Radverkehr, Strassenverkehrstecchnik, nr. 6/2002.

Bjørnskau, T. m.fl. (2012). Sykling mot enveiskjøring. Effekter av å tillate toveis sykling i enveisregulerte gater i Oslo, TØI.

Chalanton, I. & Dupriez B. (2014). Safety aspects of contraflow cycling - Detailed analysis of accidents involving cyclists on cyclist contraflows in the Brussels-Capital Region, VIAS.

Hülsen, H. (1993). Unfälle mit Radfahrern in Bayern, Beratungsstelle für Schadenverhütung, Mitteilungen, Nr. 33, Köln.

Høye, A. m.fl. (2020). Trafikksikkerhetshåndboken, TØI, https://tsh.toi.no/.

PRESTO (2012). Contraflow cycling, Promoting cycling for everyone as daily transport mode.

11 Summary

The effect of the 10 selected road technical solutions for cyclists' safety, sense of security and passability are summarised in the subsequent 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

The 10 road technical solutions are divided into 23 variants of solution.

The overview shows that most variants of solution typically have both positive and negative effects. Thus, there are only very few solutions which have a positive effect on both safety, experienced sense of security and traffic flow. The solutions, where this is the case, are: Before-green in signal-controlled intersections, refuges at bus stops, safety zones at street parking and contraflow cycling permitted in one-way streets. Thus, these are solutions, which are unambiguously good cycle solutions.

Some of the road technical solutions have no positive effects in relation to road safety, experienced sense of security and traffic flow. In these cases, however, the solutions can be improved by the use of additional measures.

For the remaining solutions, it is necessary, prior to selecting a solution, to prioritise between safety, experienced sense of security and traffic flow for the cyclists.

Finally, the overview shows that often the effects are "likely", and rarely as well documented in studies, as it being possible to state an effect estimate in a credible way. It is particularly the effects on experienced sense of security and traffic flow, which are rarely quantified.

Measures	Road safety	Sense of security	Passability
Truncated cycle lane in signal-controlled intersections			
Regular terminated cycle lane in signal-controlled intersections			
a. Next to a separate right-turn lane			
b. Next to a combined straight ahead and right-turn lane			
Cycle lane between straight ahead and right-turn lane			
Two-way cycle lanes in intersections			
a. Separately controlled signal control			
b. T-junction controlled by duty to give way, where drivers have the duty to give way			
c. T-junction controlled by duty to give way, where cyclists have the duty to give way			
Cycle signals in intersections			
a. Separate control			
b. Before-green			
c. After-red			
d. Right-turn arrow			
Cycle infrastructure at bus stops			
a. Bus stop at cycle track			
b. Bus stop at cycle lane			
c. Bus island			
Car parking alongside cycle tracks and cycle lanes			
a. Parallel parking alongside cycle track			
b. Angled or perpendicular parking alongside cycle track			
c. Parallel parking alongside cycle lane			
d. Safety zone			
e. No parking			
Divided path and shared use path			
a. Divided path			
b. Shared use path			
2 minus 1-road			
Contraflow cycling permitted			

Danish Road Directorate holds offices in:

Aalborg, Fløng, Middelfart,
Næstved, Skanderborg
and København

More information is available at
vejdirektoratet.dk

Vejdirektoratet
Danish Road Directorate
Carsten Niebuhrs Gade 43
1577 Copenhagen V

Telephone +45 7244 3333
vd@vd.dk
vejdirektoratet.dk

Vejdirektoratet
Danish Road Directorate