Infrastructure for pedestrians and cyclists

SWOV fact sheet, November 2020

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Summary

A safe infrastructure is of vital importance to pedestrians and cyclists. In 2010-2019, 40% of the number of road deaths were pedestrians or cyclists. In 2018, they even made up 69% of the number of seriously injured road users. If pedestrians or cyclists are involved in crashes with motorised vehicles driving faster than 30km/h, they run a significant risk of severe or fatal injuries. The design of residential areas and homezones should therefore ensure that driving speed does not exceed 30km/h.

If driving speed exceeds 30 km/h, footpaths and bicycle tracks should physically separate slow traffic from heavy motorised traffic. A one-way bicycle track is preferable to a two-way bicycle track, since the latter increases the number of crashes at priority intersections. To prevent single-bicycle crashes, it is important that that there are no obstacles cyclists can crash into, that road alignment is visually guided, e.g., with edge and centre line marking for bicycle tracks for instance, that the bicycle track is sufficiently wide, that the road surface is even, skid-resistant, free of cracks and clean, and that road shoulders and kerbs are forgiving.

Pedestrians and cyclists can cross 50km/h roads most safely at intersections or roundabouts, with roundabouts being safest. At 50km/h road sections, pedestrians can cross the road more safely at pedestrian crossings than at sections without these crossings and most safely at signalised crossings. Pedestrian crossings are ideally implemented under the right conditions (e.g., a crossing length of two lanes at most) and with additional measures (e.g., to limit the speed of cross traffic to 30km/h). Road safety at signalised crossings improves by making them more conflict-free. Similar to bicycle traffic lights, pedestrian traffic lights may also be safer when positioned at the beginning of the crossing, which is called the Maastricht set-up.

1 How many casualties are there among pedestrians and cyclists?

Between 2010 and 2019, an annual average of 59 pedestrians and 194 cyclists died in road crashes (Source: Statistics Netherlands datalink), also see SWOV fact sheet *Road deaths in the Netherlands*. This was respectively 9% and 31% of the total number of road deaths in that period. As shown in *Figure 1*, the number of road deaths among cyclists has hovered around this number since 2000, while the number of pedestrian road deaths has decreased.

On account of the (international) definition of a road crash (introduced by Statistics Netherlands in 1926), the figures for pedestrians and cyclists may not be compared: a crash is only a road crash when it involves a moving vehicle. When cyclists fall off their bicycles or crash into an obstacle, this is classified as a road crash. When pedestrians take a fall at the exact same location or bump into obstacles or other pedestrians[1], this is not classified as a road crash. The estimated annual number of deaths by these pedestrian falls and collisions is approximately 75 [1].
Figure 1 only includes the number of road deaths according to the official definition (so excluding deaths by pedestrian falls and collisions).

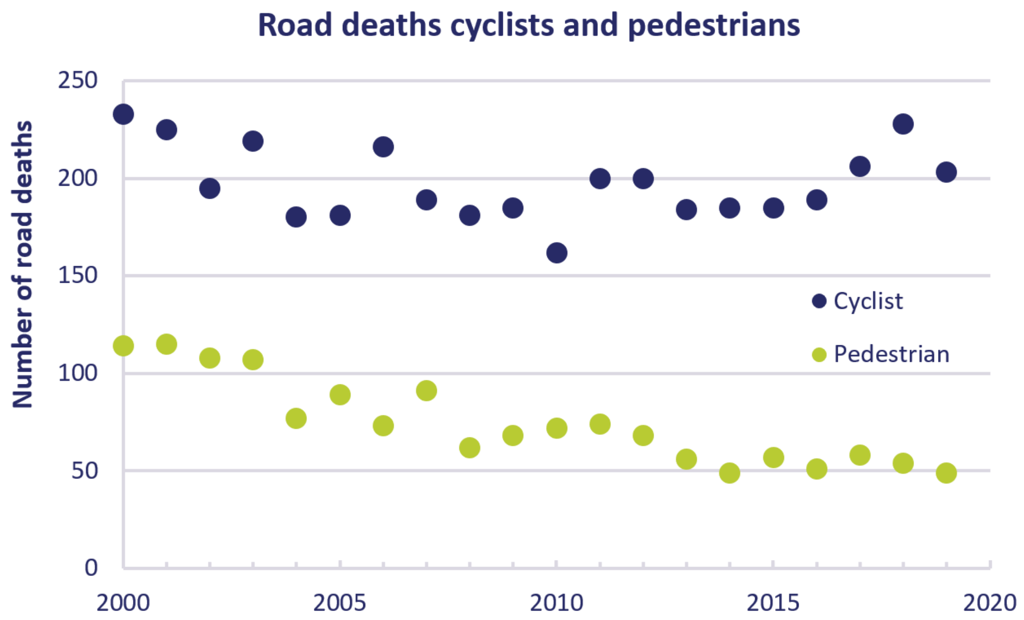

Figure 1. Number of road deaths among cyclists and pedestrians between 2000 and 2020 (Source: Statistics Netherlands datalink).

Figure 2 illustrates the distribution of the number of serious road injuries in 2018[2] and shows that more than half the serious injuries were sustained by casualties of bicycle crashes which did not involve a motor vehicle as crash opponent. The share of cyclists is 64% and the share of pedestrians is 5% of the total number of serious road injuries. Yet, among pedestrians, the number of serious injuries after falls and collisions is about five times higher than the number of serious injuries in road crashes [1]. More information about casualties among pedestrians and cyclists can be found in SWOV fact sheet *Pedestrians* and fact sheet *Cyclists*.

[1] In this fact sheet, pedestrian road crashes are defined as crashes involving a moving vehicle, unless explicitly stated that a different definition is used.

[2] Because of a change in the method of calculating the number of serious road injuries in 2018, the time period used for road deaths cannot be applied here and, therefore, the figures are restricted to 2018.

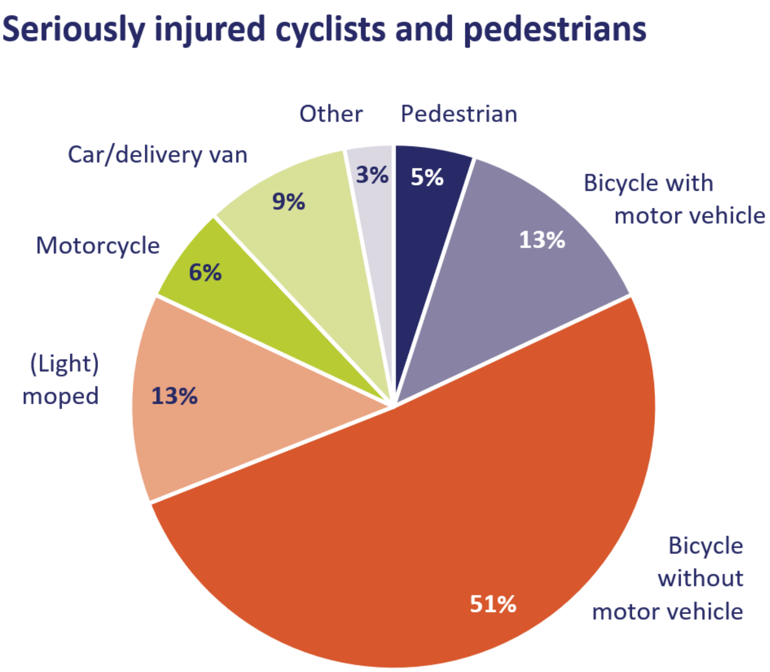

Figure 2. Distribution of the number of serious road injuries among cyclists and pedestrians by mode of transport in 2018 [2].

2 What type of infrastructure is available to pedestrians and cyclists?

Road sections

For pedestrians and cyclists, there are physically separate footpaths and bicycle tracks. According to the 1990 Traffic Code (RVV 1990), pedestrians should use the pavement or footpath. If both are lacking, they should use the bicycle track or, if that is absent as well, the road shoulder. A pedestrian precinct is an area which should really only accommodate pedestrians and sometimes cyclists. These areas are often located at shopping centres. At designated times of day, trucks are allowed for delivering supplies. Physical barriers and several types of signage may be used [3].

For cyclists, use of bicycle tracks is mandatory. They will only use the carriageway if there is no mandatory bicycle track and they may use a non-mandatory bicycle lane if that is present. A bicycle/moped track is a bicycle track that is also mandatory for mopeds. A bicycle lane, marked by bicycle pictograms, is a part of the carriageway visually separated by continuous or broken lines. Other road users may not stop their vehicles in these lanes (RVV 1990). Road authorities may suggest a bicycle lane by means of lines, but without bicycle pictograms, but this is not covered by traffic regulations and is discouraged [4]. A bicycle street is a road that is designed to combine a through-function for cyclists and a access function for cars [5]. The design is intended to persuade drivers to adjust their behaviour to the presence of cyclists, for example by lowering their speeds. In the Netherlands, there are no specific traffic regulations for road users of bicycle streets.

Pedestrian crossings within road sections

Besides road section infrastructure, there is also infrastructure for pedestrian crossings within road sections (other than intersections). In RVV 1990, zebra crossings are called pedestrian crossings, see the example in *Figure 3*. Some of them are signalised. For cyclists, priority at crossings is arranged similarly to priority for motorised vehicles, e.g., by shark teeth on the road surface or by traffic lights. In addition, channel and block markings may indicate where pedestrians and cyclists may cross, without the markings assigning priority.

Figure 2. Example of a zebra crossing (Photograph: Paul Voorham).

Intersections

The provisions described for pedestrian crossings within road sections may also be applied at intersections and roundabouts. Bicycle lanes/tracks and footpaths/pavements may connect to intersections. A bicycle lane may connect to a 'bike box', where cyclists may position themselves ahead of motorised traffic (see *Figure 4*). Signalised intersections may have pedestrian and cyclist traffic lights. Pedestrians and cyclists may cross when the lights are green for them and red for other traffic, i.e. exclusive traffic signal phasing. Yet, some signalised intersections have concurrent signal phasing, when the lights are green not only for vehicles taking a left or right turn, but also for pedestrians (and/or cyclists) crossing the road the vehicles turn into.

Figure 3. Example of a bike box (Photograph: Paul Schepers).

3 Which road users may use footpaths, bicycle tracks and lanes?

Table 1 describes which modes of transport RVV 1990 allows on footpaths, bicycle tracks or bicycle lanes. The third column shows possible speed limits and the fourth column possible conditions of use. 'Motorised vehicles for the disabled' include electric wheelchairs and mobility scooters for example (also see [6]). Rules for specific types of vehicles may be derived from the regulations for the main modes of transport in *Table 1*, for example for:

- Pedestrians: roller-skates, scooters, walking frames, a moped that is pushed along;
- Light mopeds: vehicles that are designated as 'special mopeds', such as Segways;
- Mopeds: speed pedelecs.

In some parts of Amsterdam, light-moped riders have been redirected from the bicycle track to the carriageway since April 2019. This exception is indicated by a subsign.

Table 1. The modes of transport permitted on footpaths/pavements and bicycle tracks/lanes in the Netherlands, speed limits (differentiated by urban roads and rural roads for disabled person's vehicles and mopeds), possible conditions and signage.

Infrastructure type	Permitted modes of transport	Speed limit by mode of transport and road type	Possible condition by mode of transport	Sign in RVV 1990
Footpath/ pavement	Pedestrian Motorised disabled person's vehicle	n.a. 6 km/h	n.a.	
Mandatory bicycle track	pedestrian bicycle/pedelec Light moped Motorised disabled person's vehicle	n.a. n.a. 25 km/h 30 km/h urban road; 40 km/h rural road	Footpath/pavement lacking	
Mandatory moped/bicycle track	Pedestrian Bicycle/pedelec Light moped Moped Motorised disabled person's vehicle	n.a. n.a. 25 km/h 30 km/h urban; 40 km/h rural road 30 km/h urban; 40 km/h rural road	Footpath/pavement lacking	
Non-mandatory bicycle track	Pedestrian Bicycle/pedelec Light moped Motorised disabled person's vehicle	n.a. n.a. 25 km/h 30 km/h urban; 40 km/h rural road	Footpath/pavement lacking Electric propulsion	
Bicycle lane	Bicycle/pedelec Light moped Disabled person's vehicle	 25 km/h 45 km/h or less if the road speed limit is lower		n.a.

4 How to design infrastructural provisions for pedestrians and cyclists to make them as safe as possible?

Ideally, pedestrians and cyclists walk and cycle in 30km/h zones and home zones (15 km/h) or on physically separate footpaths/pavements and bicycle tracks along distributor roads (for ease of reference, hereafter referred to as 50 km/h roads). They may cross 50km/h-roads at intersections where speed is limited to 30 km/h. When there are crossings at road sections of 50km/h-roads, though, zebra crossings for instance, it is important that crossing traffic travels at a maximum speed of 30 km/h. Footpaths/pavements and bicycle tracks should be designed and maintained in such a way that chances of pedestrian falls or collisions and single-bicycle crashes are minimal, for example by not creating obstacles, and by means of sufficiently wide provisions and a plane road surface. *Table 2* and *Figure 5* summarise the Sustainably Safe road types and what the design principles of Sustainable Safety entail for an ideal design for pedestrians and cyclists.

Table 2. Position of pedestrians and cyclists in the urban area by road type according to Sustainable Safety.

Road type	Speed limit	Position of pedestrians and cyclists on road sections	Position of pedestrians and cyclists for crossing
Access road	15, 30 km/h	Mingling with motor vehicles	Everywhere
Distributor road	50, 70 km/h	Separated by bicycle track or footpath	Intersections or roundabouts
Through-road	100, 120 or 130 km/h	Not allowed	Grade-separated (tunnel or bridge)

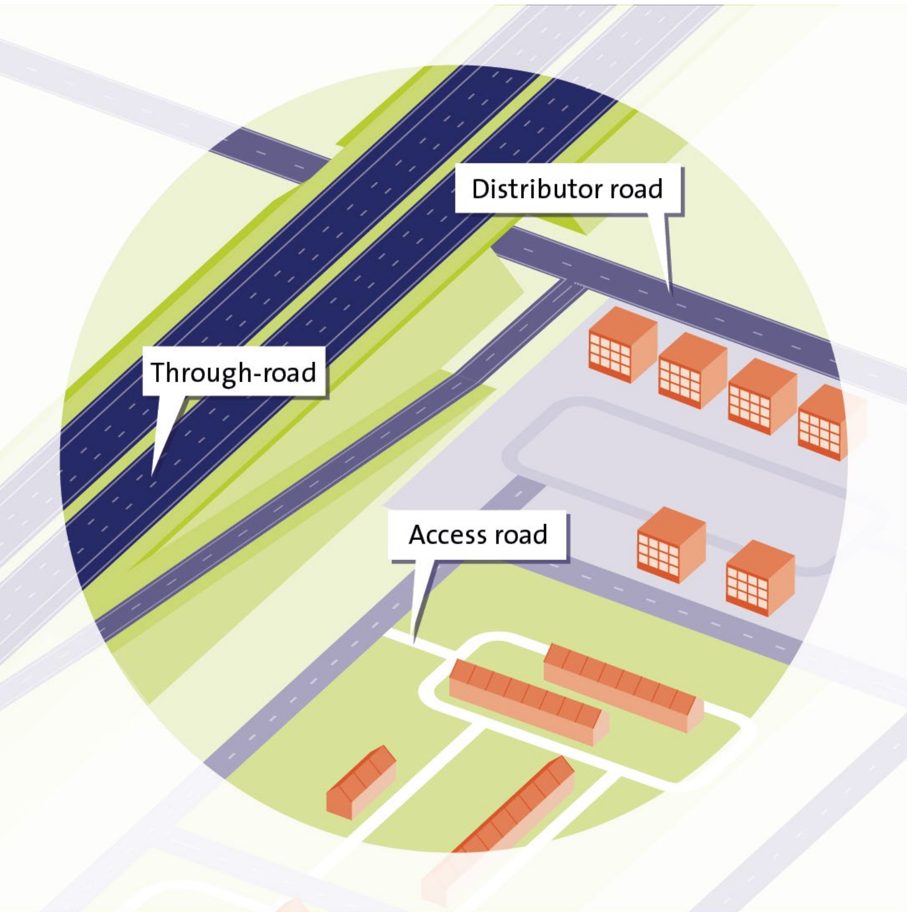

Figure 4. Functional road classification.

Infrastructure for safe interaction with motorised traffic

Sustainable Safety includes a.o. the design principles of functionality and (bio)mechanics, see SWOV fact sheet Sustainable road safety.

Functionality implies that mingling of and exchange between heavy motorised traffic, pedestrians and cyclists takes place in residential areas (with a speed limit of 15 or 30 km/h) and at intersections of distributor roads.

(Bio)mechanics implies that driving speeds are adapted to the most vulnerable road users, such as pedestrians and cyclists. At places where vulnerable road users mingle with heavy motorised traffic (in residential areas and at intersections), the speed limit is 30 km/h, because the risk of a fatal crash considerably increases when collision speed is higher than approximately 30 km/h [7]. At intersections where pedestrians and cyclists may meet heavy motorised traffic, the ideal speed limit is therefore 30 km/h. This could be enforced by means of raised intersections [8] or roundabouts (see SWOV fact sheet *Roundabouts*). On 50km/h-roads, pedestrians and cyclists should be physically separated from motorised traffic by means of footpaths and bicycle tracks. These roads are crossed by means of intersections because driving speed at road sections is too high. The location of important walking routes and main cycling routes implies that 50km/h-road sections may also need crossing facilities.

The Administrative Provisions Decree determines that, in the urban area, roads with a 30km/h- or 50km/h-speed limit should have zebra crossings. The risks of high speeds at road sections have resulted in Recommendations for Urban Road Facilities and other CROW publications [9] [10] [11] restricting the use of zebra crossings to certain conditions (for example, only at those locations where a relatively large number of pedestrians cross the road) and to add countermeasures (such as lowering the speed of motorised traffic at the crossing location to a limit of 30km/h and to add a plateau). In 30km/h-zones, zebra crossings are, in principle, not implemented, because a credible road design implies that safe crossing should be possible at every zone location.

Infrastructure for preventing pedestrian falls or collisions

Compared to the cycling infrastructure, little attention has yet been paid to the pedestrian infrastructure to prevent falls, since these are not defined as road crashes. However, requirements to make footpaths accessible to groups such as wheelchair users, blind and visually impaired road users have been set. Examples of requirements from the Accessibility manual [12] are wide footpaths, sufficiently large storage areas on median islands and entry and exit ramps for wheelchair accessibility. As yet, too little research is available to allow for solid conclusions, but improving accessibility is likely to also help prevent pedestrian falls. Research into these falls and collisions suggests that steps, loose flagstones, potholes, winter slipperiness, and litter play a role [1] [13].

To prevent single-bicycle crashes, it is important that there are no obstacles to crash into, that road alignment is visually guided with edge and centre line markings for bicycle tracks for instance, that the infrastructure is sufficiently wide, that the road surface is even, skid-resistant, free of cracks and clean, and that road shoulders and kerbs are forgiving [14] [15] [16]. Details of the design principles for safe bicycle tracks have been published in ‘Components for a comfortable and forgiving bicycle track’ [17].

5 How safe are zebra crossings and other crossing facilities?

If a zebra crossing or a signalised crossing has been designed according to the guidelines, it is safer for pedestrians to cross distributor roads at those crossings and not elsewhere [18] [19]. A signalised crossing is safest [18] [20]. Mere zebra marking do not have enough effect; because of the shallow angle of a driver's glance at the road surface, road markings are hard to see from a distance [21].

Signalised crossings

Traffic lights can achieve time separation of pedestrians (and cyclists) from heavy motorised traffic. Conflict-free traffic lights with exclusive signal phasing are safest [11] [22]. Concurrent signal phasing may occur, for example, when the lights are green not only for vehicles taking a left or right turn, but also for pedestrians (and/or cyclists) crossing the street the vehicles turn into. At intersections where a lot of older people tend to cross, they should be permitted enough time to cross the road; after all, their walking speed is lower. Coffin and Morrall [23] advise 1.0 m/s (3.6 km/h) as a starting point. In comparison: the Dutch Traffic light regulation prescribes basing calculations on a walking speed of 1.2 m/s [24].

In the Netherlands, the pedestrian traffic light is usually mounted at the end of the crossing but, following its position in the city of Maastricht, a position at the beginning of the crossing similar to that for other traffic is also possible (see *Figure 3*). Since 2019, this position has been allowed following the new article 79a in the Traffic light regulation. In the United Kingdom this position has been applied for several decades under the name of 'Puffin crossing' (*P*edestrian *U*ser *F*riendly *In*telligent crossing [25]) and has improved road safety for pedestrians [26] [27]. Sensors follow pedestrians at crossings to determine the time they need to cross, so that driver traffic lights turn green sooner when pedestrians cross faster, and later when pedestrians cross more slowly [25]. A Puffin crossing causes less confusion about the green phase of the traffic light for one's own lane (prevents 'green lure') and is more visible for visually impaired road users [28]. Possible doubt about the moment when drivers start driving used to be mentioned as an objection, but SWOV research showed that a slight majority of pedestrians prefer pedestrian lights at the beginning of the crossing, e.g., because visually impaired road users are better able to see the lights then [29].

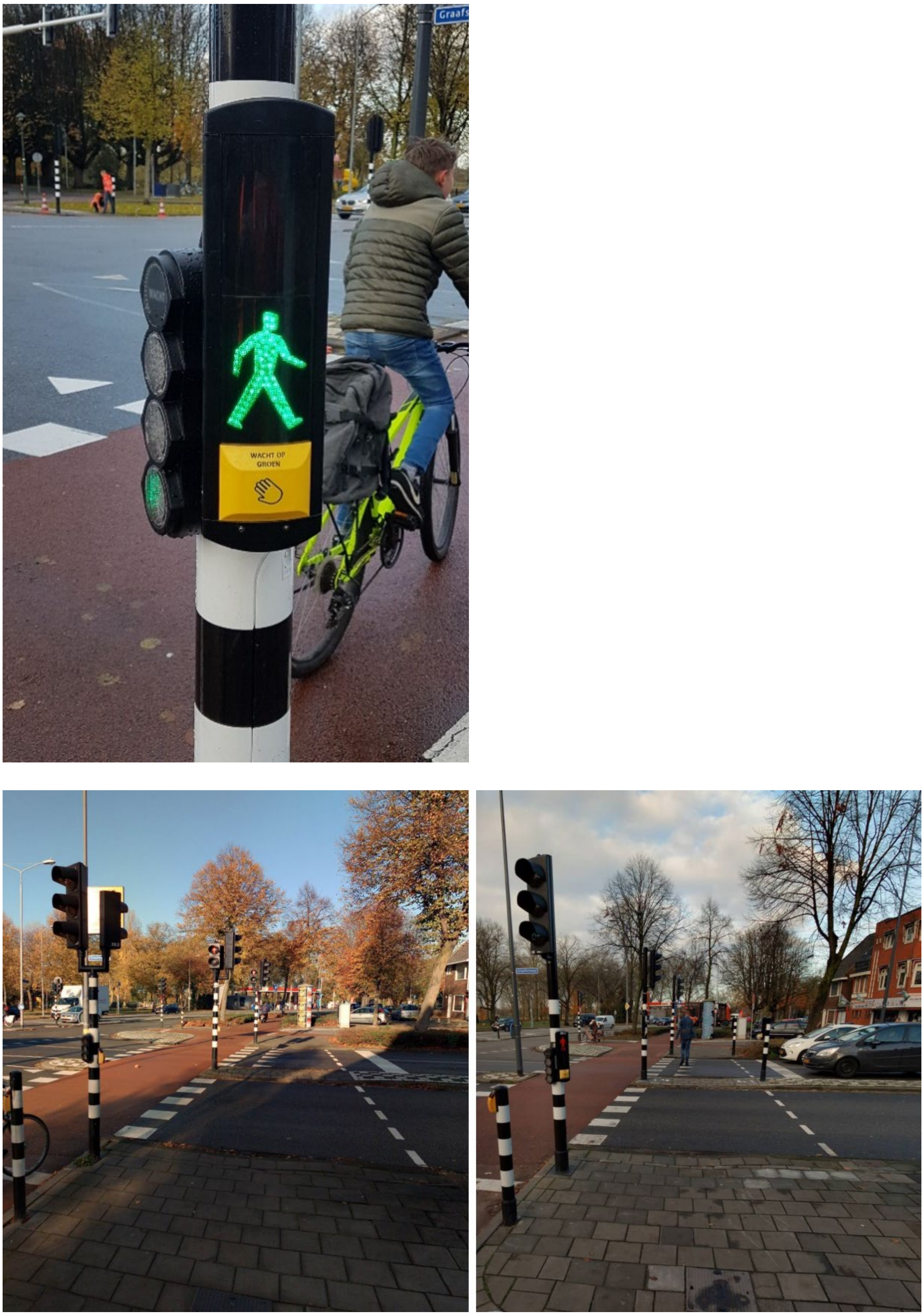

Figure 5. Above: pedestrian light at the beginning of the crossing, the 'Maastricht position' (Photograph: Eric Greweldinger). Below: Before and after installing pedestrian lights at the 'Maastricht position' in the city of Den Bosch (Photograph: Cyclomedia).

Research into the safety effect of zebra markings

It is hard to draw valid conclusions about the effect of zebra markings. There is little high-quality research, and comparisons between studies from different countries are hard because of judicial and contextual differences. A lot of studies do not take the number of pedestrians and motor vehicles at a crossing into account, nor design characteristics such as physical speed reduction measures and conspicuity, and zebra markings are sometimes included in the broader category of 'marked crosswalks' [18] [19]. For the situation in the Netherlands, an older SWOV study concludes that, compared to road sections without crossings, it is safer to cross at a zebra crossing and safest at a signalised crossing [20]. Existing research may lead to the cautious conclusion that zebra markings alone (at a crossing length of two lanes at most) have little effect on road safety, but zebra markings combined with measures such as signage and physical speed reduction could have a positive effect [9] [18] [19] [20] [30].

6 How safe is a pedestrian precinct?

A pedestrian precinct is an area that uses physical barriers and signage to exclusively reserve access to pedestrians, and sometimes to cyclists and loading/unloading traffic. Research into the road safety effects of pedestrian precincts dates back several decades. It suggests that road safety in and around pedestrian precincts improves because the number of conflicts between pedestrians and motor vehicles decreases [18]. Shopping streets often have a lot of side streets from which (motorised) traffic may exit and trucks and delivery vans restrict the visibility of pedestrians during loading and unloading. Establishing pedestrian precincts will prevent those problems.

Behavioural observations (speed differences and conflicts) by Fietsberaad (Knowledge centre for cycling policy of the Dutch governments) [3] suggest that cycling in pedestrian precincts is safe and practicable, provided the number of pedestrians per hour per metre of profile width is restricted to 100. At 100 to 200 pedestrians per hour per metre of profile width, a 'segmented profile' (with a separate strip for cyclists) is advisable, and at a density above 200, joint use of the area is unadvisable. For the number of cyclists, no critical limit has been set. Studies from Germany and the UK correspond to the Dutch findings by Fietsberaad [31] [32].

Figure 6. Entry to the pedestrian precinct in the city of Apeldoorn (Photograph: Paul Schepers).

7 Is Shared Space a safe solution for pedestrians and cyclists?

Shared Space implies that all modes of transport share the road space on the basis of eye contact and non-verbal communication and only to a minimum extent on the basis of signage and regulations [33]. Traffic conflicts would supposedly be best prevented by integrating *uncertainty* in the traffic situation while using as few signs and signals as possible. Road users would allegedly pay more attention and should be able to solve situations together. Shared Space intends to realise design credibility with the help of 'natural' elements. So far, it has not been scientifically established whether a Shared-Space design for pedestrians and cyclists is safer than a 'traditionally' designed space. Such an evaluation is needed to justify large-scale implementation [34].

SWOV fact sheet *Sustainable Road Safety* specifies the Shared-Space approach in more detail.

Figure 7. Example of Shared Space in the city of Drachten (Photograph: Fietsberaad).

8 How safe are bicycle highways and bicycle streets?

Solid conclusions about the road safety of bicycle highways and bicycle streets cannot yet be drawn. A bicycle highway, called a ‘fast cycle route’ in the Design Guide for Bicycle Traffic, is a regional main itinerary designed to the highest standards to accommodate long-distance bicycle trips [4], see Figure 9 for an example. A bicycle street combines two functions: a through-function for cyclists (main cycle route, fast cycle route) and an access function for drivers [5]. See *Figure 10* for example.

In bicycle streets, a road sign may emphasise that motor vehicles should behave as ‘guests’, but both bicycle street and road sign have no legal status, see CROW-Fietsberaad [5] for more design recommendations. A fast cycle route may be a bicycle street, a solitary bicycle track or a bicycle lane along a carriageway. They may be realised in such different ways that their correlation to road safety is impossible to ascertain conclusively. For bicycle streets, this goes to a lesser extent, since they can have one or two strips and, if required, speed reduction and traffic circulation measures to restrict the number of motor vehicles.

In the Netherlands, there is no crash research available to determine the safety of bicycle streets. In 2017, CROW-Fietsberaad conducted observational research in 11 streets, counting 6,600 encounters with motor vehicles in 33 hours. No near-crashes occurred. About 5% of the encounters were classified as troublesome or dangerous, particularly tailgating a cyclist was rather frequent [5]. According to Mansvelder, Delbressine and Dijkstra [35], characteristics such as priority for bicycle street traffic and the use of asphalt are incompatible with the Sustainable Safety vision of residential areas, see SWOV fact sheet 30 km/h zones. In eight of the bicycle streets studied by Delbressine [36] a large proportion of drivers exceeded the 30km/h-speed limit.

The road safety effects of bicycle streets should also be considered at network level. Cyclists can pass through residential areas via bicycle streets instead of going round them along distributor roads. This is also known as ‘unbundling of the car and bicycle network’ [4]. Cities where cyclists pass through residential areas and less often along distributor roads prove to be safer for cyclists, but in reaching this conclusion, use of bicycle streets was not explicitly explored [15] [37].

Figure 8. Example bicycle highway (Photograph: Fietsberaad).

Figure 9. Example bicycle street (Photograph: Paul Voorham).

9 Is a bicycle track safer than a bicycle lane?

A bicycle track (physically separated from the carriageway, see *Figure 11*) is safer than a bicycle lane (visually separated from the carriageway, see *Figure 3*). Internationally, not much research has been done into the effect of these provisions on road safety while taking into account the number of cyclists and motor vehicles. On the basis of an international literature review, Thomas and DeRobertis [38] conclude that bicycle tracks may improve road safety if measures to increase road safety at intersections are taken. In the Netherlands, the safety of bicycle tracks and bicycle lanes was compared by Welleman and Dijkstra [39], based on the number of registered crashes in fourteen cities between 1973-1977. They distinguished major junctions where arterial roads intersect ('at-grade junctions'), the road sections in between and the 'intervening junctions' on these road sections. Both on road sections and intervening junctions, bicycle tracks proved safer than bicycle lanes. In the current situation, intervening junctions would mostly be priority junctions. A more recent study confirmed that, at priority junctions, bicycle tracks are safer than bicycle lanes [15]. In addition, a still more recent study showed that bicycle tracks are safer than bicycle lanes on roundabouts as well [40]. In a study in Amsterdam, SWOV is again comparing bicycle tracks and bicycle lanes. First results confirm that bicycle tracks are safer than bicycle lanes.

Figure 10. Bicycle track (Photograph: Paul Voorham).

10 Are two-way bicycle tracks as safe as one-way bicycle tracks?

Two-way bicycle tracks are less safe than one-way bicycle tracks and, therefore, one-way bicycle tracks have been preferred in design recommendations and guidelines for some time now [4] [41] [42]. The heading of this section refers to bicycle tracks alongside carriageways and not to solitary bicycle tracks. In the 70s, two-way bicycle tracks in the urban area were uncommon, and in the rural area the length of one-way bicycle tracks also exceeded that of two-way tracks [42] [43]. In 2014, an inventory showed that, by then, 62% of the length in the urban area and 79% of the length in the rural area was taken up by two-way bicycle tracks [44]. Methorst et al. [45] published a review article in which the problems involved in two-way bicycle tracks were summarised. On road sections, two-way bicycle tracks increase the risk of head-on crashes between cyclists, and between cyclists and (light) moped riders [14]. Drivers who turn right to a distributor road from an access road on priority intersections often only look to the left, the direction vehicles normally come from. Cyclists on two-way bicycle tracks that, from the driver's point of view, come from the right are therefore overlooked. This problem concerning expectations and glance behaviour was first observed in Sweden [46] and has since also been observed in the Netherlands [47]. On average, the risk that a cyclist on a priority road is hit by a motor vehicle at a priority intersection is 75% higher for two-way bicycle tracks than for one-way bicycle tracks [15]. Research into blind-spot crashes has uncovered an additional problem in situations where a truck crosses a two-way bicycle track before entering a priority intersection or roundabout. Seen from the access road or from one of the arms of the roundabout, cyclists to the right of a truck may be in the driver's blind spot which may result in blind-spot crashes [48].

Figure 11. Two-way bicycle track with a cyclist coming from the right side from the perspective of the side road of the main road where a cyclist crosses a side street and may be overlooked by drivers coming from the side street (Photograph: Paul Schepers).

11 What is safer for pedestrians and cyclists, a roundabout or other type of intersection?

Roundabouts are safer for pedestrians and cyclists than other types of intersections [8] [22]. Cyclist safety is most strongly improved by roundabouts with bicycle tracks [40]. Cyclist safety and the correlation with priority rules are discussed in SWOV fact sheet *Roundabouts*.

12 Are Dutch bicycle tracks too crowded?

At specific locations and times of day, particularly in major cities, the width of bicycle tracks is insufficient for the number of users. Whether congestion on bicycle tracks adversely affects cyclists' road safety is unknown. A letter to the Dutch Lower House of Parliament states that possible problems caused by congestion on bicycle tracks strongly differ between regions [49]. Parties that have questioned the minister of Infrastructure and Water Management [49] on this issue, indicate that the experienced congestion is often caused by speed differences between the users of bicycle tracks, for example between bicycles and light mopeds, which is especially relevant in major cities (also see the question *What is safer for light mopeds, carriageway or bicycle track?*), and between cyclists and racing bikers on recreational bicycle tracks. SWOV research has shown that there is indeed a great variety of road users on bicycle tracks [50]. Light mopeds are faster and wider than standard bicycles, and an overwhelming majority ride faster than permitted (25 km/h) [51] and overtake other road users more often.

On bicycle tracks, traditional city bikes are used by about 90% of cyclists. The number of pedelecs is increasing, but, in speed, they differ less from traditional city bikes than light mopeds do (see the question *How big a problem is the difference in speed, mass and size of vehicles on bicycle tracks?*). The large share of traditional city bikes determines behaviour on bicycle tracks when they are crowded. That is why at crowded locations speed varies less than at quiet locations [50] and why fewer cyclists ride against the compulsory direction illicitly [44]. According to CROW guidelines [4], minimal widths of bicycle tracks should depend on the number of cyclists that use them. In major cities, and at specific locations and times of day, the width of the bicycle track is insufficient [50] [52], but crash studies into the correlation between congestion and safety on bicycle tracks are not available yet. For now, without new research, congestion is a subjective concept. Mention is also made of 'Perceived congestion', which depends on individual, social and physical factors. Congestion is mainly perceived to be a problem in major cities, and sometimes cyclists adapt their routes or their time of departure or even decide to choose a different mode of transport [53] [54].

13 How big a problem is the difference in speed, mass and size of vehicles on bicycle tracks?

Bicycle tracks are not only used by cyclists, but also by quite a lot of light-moped riders, and bicycle/moped tracks by moped riders as well. Speed and mass of the average (light-)moped rider differ considerably from that of the average cyclist [51] [55] and that is why these three modes of transport mostly determine the answer to the question to what extent speed, mass and size differences cause problems on bicycle tracks.

Early 2019, there were about 750,000 light mopeds, 450,000 mopeds and 17,000 speed pedelecs [2]. There are no statistics about cargo bikes. Their number seems to grow but, in a branch analysis, RAI Association [56] still calls it a niche market serviced by small manufacturers. Mopeds and light mopeds are over 50 kilos heavier and, including mirrors, 15 centimeters wider than pedelecs and bicycles. On bicycle tracks, light mopeds ride an average 32 km/h, approximately just as fast as mopeds before introduction of the Moped On the Carriageway measure in 1999 [51] [57]. So, light mopeds ride considerably faster than cyclists on ordinary bicycles (18 km/h) or pedelecs (21 km/h), see SWOV fact sheet *Pedelecs and speed pedelecs*.

The magnitude of the adverse road safety effect of these differences between vehicles on bicycle tracks is hard to quantify, but the evaluation of the Moped On the Carriageway measure showed that road safety improved after mopeds had been redirected from the bicycle track to the carriageway in urban areas in 1999. The number of road injuries in crashes with mopeds decreased by 15%. This not only concerns the moped riders themselves, but also pedestrians and cyclists who, as crash opponents, may also get injured. On bicycle tracks in the urban area, the number of crashes between moped riders and cyclists decreased and, at intersections, the number of crashes also decreased because, before the measure was introduced, drivers did not take account of high speeds of moped riders on bicycle tracks [39] [57] [58]. Outside the urban area, cyclists and moped riders still mingle on bicycle/moped tracks but, there, bicycle tracks are mostly quieter and the speed differences between mopeds and motor vehicles on the carriageway would be too great.

The question *What is safer for light mopeds, carriageway or bicycle track?* elaborates the consequences of speed and mass differences between light mopeds and other traffic. See SWOV fact sheet *Pedelecs and speed pedelecs* for differences between speed pedelecs and other traffic.

14 What is safer for light mopeds, carriageway or bicycle track?

Track records of the Moped On the Carriageway measure, introduced in 1999, suggest that also for light-moped riders the carriageway is safer than the bicycle track, provided they wear helmets when using the carriageway [59]. On the basis of in-depth studies of light-moped crashes, the question has been raised whether speed differences between light-moped riders and motor vehicles on 50km/h carriageways are not too great [60]. In Amsterdam, initial track records of light mopeds on the carriageway show that carriageways are safer than bicycle tracks for helmeted light-moped riders [61].

In 2018, the Decision Local separation bicycle and light moped was adopted, which enabled road authorities to designate roads where helmeted light-moped riders should use the carriageway instead of the bicycle track if so indicated by means of subsigns. Since April 2019, light-moped riders in Amsterdam have been obliged to use the carriageway on most roads within the A10 ring road. These are mostly distributor roads with a speed limit of 50 km/h. An initial evaluation by the municipality of Amsterdam [61] shows that the number of light-moped trips has decreased by about 50%, and the number of registered crashes has decreased even more. Figures from the Netherlands Vehicle Authority give rise to the conclusion that light-moped possession in the area where the measure applies has decreased, while moped possession has also slightly dropped. A conflict analysis at three intersections suggests that the number of conflicts per crossing (light) moped has also dropped [61]. What is needed to draw more definitive conclusions is a longer period of evaluation and introduction of the measure in other cities.

15 Does introducing a speed limit for bicycle tracks make sense?

On bicycle/moped tracks, a speed limit for mopeds already applies: 30 km/h in the urban area and 40 km/h in the rural area. A light moped is a moped that is allowed to go at a maximum speed of 25 km/h (and that should have a corresponding construction speed), on bicycle tracks as well. A speed limit for all types of vehicles on bicycle tracks could help limit speed differences, but whether this is feasible and enforceable remains to be seen. To enable the introduction of this measure, speedometers for bicycles should become mandatory, as they already are for (light) mopeds. Considering the track records of light mopeds, the extent to which this maximum speed will be complied with and whether it will be enforceable is doubtful. After enforcement of the speed limit of 25 km/h had been stepped up in Amsterdam in 2013, the speed of 85% of light-moped riders was 39 km/h [51].

16 How may infrastructural conditions for pedestrians and cyclists become safer?

Pedestrian crossings

Not all zebra crossings comply with the recommended guidelines [9] [10] [11]. The following recommendations may help improve their safety:

- Speed: ensure that the maximum speed of motorised traffic at the pedestrian crossing is 30 km/h, for example by raising the crossing by means of a plateau.
- Traffic: only use zebra markings at locations where a relatively large number of pedestrians cross the road.
- Crossing length: always implement median islands on distributor roads with two-way traffic, so that pedestrians may cross in two phases.
- Conspicuity: increase conspicuity of crossings by vertical elements, such as speed humps, public lighting and signage.

Objectives in realising safe pedestrian crossings could follow the Swedish example: 'realise a safe speed at x% of all crossings for pedestrians and cyclists, which entails that 85% of all traffic travels at a maximum speed of 30 km/h, or that the crossing is grade-separated [62]. At signalised crossings, road safety may be improved by applying exclusive signal phasing (see the question *How to design infrastructural provisions for pedestrians and cyclists to make them as safe as possible?*) and to a more wide-scale switch to the Puffin crossing (*P*edestrian *U*ser *F*riendly *In*telligent crossing [25]), which has become the standard crossing in the United Kingdom [26] [27]. At such a crossing, pedestrian traffic lights are positioned at the beginning of the crossing and they hold the green light for as long as sensors detect pedestrians on the crossing.

Cyclist crossings

Most crossing crashes with bicycles occur at priority intersections [15]. Crash risk at these intersections may decrease by implementing two-way bicycle tracks less often and speed humps for motorised traffic more often, for example by exit constructions [63] [64]. In addition, it is safer when the bicycle track at the intersection is 2 to 5 metres from the carriageway - which is sometimes called 'deflecting' the bicycle track – because, for example, cyclists will then not be in the blind spot of a truck taking a right turn [15] [65]. At signalised intersections, measures are possible to keep cyclists out of a truck's blind spot and to prevent blind-spot crashes. If road sections with bicycle lanes connect to intersections, a bike box where cyclists may position themselves ahead of other traffic may be implemented. Where bicycle lanes connect to intersections, traffic lights could give cyclists a prestart, so that their lights turn green sooner than the lights for other traffic [48].

Bicycle tracks and bicycle lanes

For cyclists, road sections with bicycle tracks are safer than road sections with bicycle lanes, because the risk of a crash with motorised traffic is lower on account of the physical separation [15] [39] [40]. Lack of safety on bicycle lanes may probably be reduced by widening them. Passing motor vehicles will then keep a greater distance to cyclists and cyclists will keep a greater distance to the road shoulder or the kerb [66]. The latter could prevent kerb crashes. Design and maintenance of bicycle tracks could also prevent single-bicycle crashes [17] [64], for example by making them sufficiently wide, removing obstacles, using visual guidance with edge marking and an even road surface and forgiving kerbs and shoulders [14] [15] [16].

Publications and sources

Below you will find the list of references that are used in this fact sheet; all sources can be consulted or retrieved. Via Publications you can find more literature on the subject of road safety.

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