Roundabouts and other intersections

SWOV fact sheet, June 2022

SWOV

Summary

An intersection is a location where roads intersect or split and where road users may change direction. There are two main groups of intersections: unprioritised intersections and prioritised intersections. At the former intersection, drivers coming from the right have right of way. Intersections may have three, four, or five legs, and they may have been designed differently. At priority intersections, right of way is controlled by traffic signs, road markings and/or traffic lights.

About one third of the road deaths on Dutch roads occur at intersections. Within the urban area, this amounts to half and outside the urban area to slightly less than a quarter of the road deaths. Among cyclists and (light) moped riders relatively many road deaths occur at intersections. A roundabout is the safest kind of intersection, because there are fewer conflict zones, because speed is lower, and impact angles are smaller than at a conventional intersection. For cyclists and pedestrians, roundabouts are also safer than other kinds of intersections; at least in the Netherlands they are. Sustainable Safety advises roundabouts at locations where two distributor roads intersect. In general, Sustainable Safety only allows conflicts between vehicles when they do not differ greatly in speed and/or mass. That is why, from a road safety perspective, speed reduction measures are needed at or near intersections

Apart from the intersections, there are also multi-level and level crossings, but these fall outside the scope of this fact sheet. At multi-level crossings, no traffic is exchanged and therefore the conflicts that occur at other intersections are avoided. At level crossings, facilities for other kinds of traffic are crossed, for example public transport facilities (see SWOV fact sheet *Public transport and level crossings*) or pedestrian and bicycle crossings (see SWOV fact sheet *Infrastructure for pedestrians and cyclists*).

1 What do we mean by intersections?

An intersection is a location where roads and traffic flows cross one another or split and where road users may change direction. Intersections come in different shapes and sizes, but are characterised by the fact that road users cross one another at the same level. A roundabout is an at-grade intersection at which traffic flows in a circular movement and where traffic already on the roundabout has right of way [1]. A comprehensive description of different intersection types can be found at the section *What are the different types of intersection?* An intersection differs from a crossing. At a level crossing different traffic flows meet, but road users may not change direction. Examples are railway crossings or pedestrian and bicycle crossings. At split-level crossings, road users do not meet.

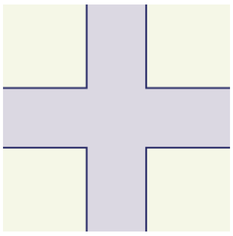
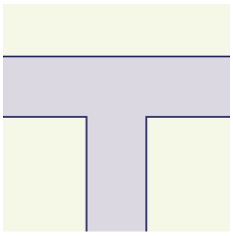
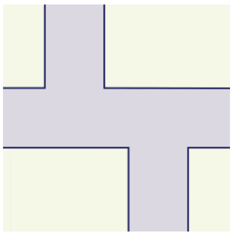
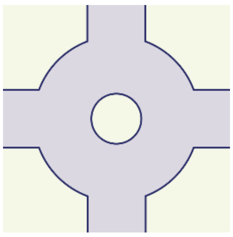
2 What are the different types of intersection?

Intersections may be subdivided by type, priority regulation and layout.

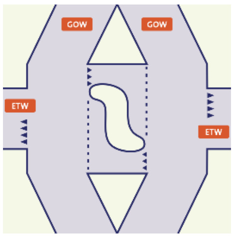
Intersection types

Table 1 shows the different intersection types.

Table 1. Intersections by type[1]*. *In the figure GOW stand for distributor road and ETW for access road.*

Intersection type	Description
	**Four-legged intersection (+ of X)** An intersection where two roads cross and traffic exchanges between both roads are possible [2]. The legs can either be at right angles (+), or not (X)
	**Three-legged intersection (Y of T)** An intersection at which one road ends as it joins another road [1] [3]. Three road sections thus meet, either in a T shape (T junction), or in a Y shape (Y junction).
	**Staggered junction** Consists of two three-legged junctions that are close but opposite to each other. It is actually a variant of a four-legged intersection. This type of intersection may only be called a staggered junction when the four roads connect [4].
	**Roundabout** This is an at-grade intersection on which traffic flows in a circular movement. Traffic on the roundabout has right of way and the roads have radial connections [1].

1 There are also gyratories, but these have not been included since they are rather scarce.

Intersection type	Description
	**Bow-legged intersection (new intersection type)*** A bow-legged intersection is a relatively new intersection type that combines elements of a roundabout and a priority intersection. An important characteristic is that the main high-volume traffic flow has right of way over the lateral flows. In this way it differs from a roundabout. A slight bend in the main carriageway ensures a speed reduction at the junction location. In addition, a median island ensures the circular movement of traffic flows and reduces speeds [5].

Intersections distinguished by priority regulations

- *Unprioritised intersection.* An intersection without specific priority regulation, but drivers coming from the right automatically have priority [1].
- *Prioritised intersection*. There are two kinds:

  1. *Priority intersection:* at which priority is arranged by traffic signs and road markings [1].
  2. *Signalised priority intersection*: this is a priority intersection at which traffic flow is controlled by traffic lights [1].

Intersections distinguished by layout

- *With or without physical speed reduction measures.* Physical speed reduction may take the form of a raised junction, speed humps or a roundabout [6].
- *With or without separate cycling facilities*. Each of the intersections discussed above either do or do not feature separate cycling facilities. There are different cycling facilities at conventional intersections within the urban area, but also at crossings, such as bicycle/moped tracks, main bicycle routes, solitary bicycle/moped tracks, bicycle streets and bicycle lanes. Outside the urban area, bicycle/moped tracks can be found at intersections, and solitary bicycle/moped tracks and bicycle routes form junctions with the main carriageway (either at-grade or grade separated by means of a tunnel or viaduct) or are integrated at the road network intersection [1].
- *With or without separate pedestrian facilities*. Intersections feature several different pedestrian facilities [1]. Some have zebra crossings and some have separate pedestrian traffic lights. Pedestrian traffic lights coincide with canalisation markings. Median islands ensure that roads can be crossed in stages. Finally, pedestrian tunnels and bridges allow for safe grade separated crossing. They are mainly located at through-roads and distributor roads.
- *With or without separate public transport facilities*. Intersections where public transport lanes cross other roads are usually priority intersections, intersections with separate traffic lights for public transport, intersections with regular traffic lights, or roundabouts to which the public transport lane connects. Public transport is given right of way wherever possible, to enhance its desired maximum flow, frequency and punctuality [1].

In practice, a lot of variations on the abovementioned intersection types exist. Uniformity of intersections is therefore limited, often because of the traffic situation on site, costs and the available space. Another reason for the lack of uniformity is that formal Dutch guidelines do not exist. Instead there are recommendations, as laid down in 'ASVV 2012'[2] (Recommendations Urban Traffic Facilities 2012) [7] and the 'Handboek Wegontwerp 2013' (Road Design Manual) [8], both by CROW.

3 How many casualties are due to crashes at intersections?

About one third of all road deaths can be attributed to intersections[3]. The share of road deaths on urban intersections (almost half) is higher than that on intersections outside the urban area (somewhat under a quarter). Among cyclists, the number of road deaths on intersections is higher than on road sections: an annual average of 54% of the total number. A second noteworthy category are (light) moped riders: half their annual number of road deaths can be attributed to intersections. For the other modes of transport, the share of fatal intersection crashes is much smaller when compared to the number of fatal road section crashes. Examples are fatal car crashes at intersections at 19% and pedestrian fatalities at 26% (see *table 2* below). *Table 2* shows the 2015-2019 average number of road deaths at intersections compared to the number at road sections, differentiated for urban or non-urban area, and for mode of transport. The table shows absolute numbers and percentages.

2. The new ASVV is expected for the autumn of 2021.
3. The term intersection is used here, but it is uncertain whether the crash took place at an intersection or crossing since the quality of the location registration in BRON is hard to determine (see the section *What do we mean by intersections?*). 'Intersection' therefore necessarily covers both locations.

Table 2. The average annual number of BRON-registered road deaths at intersections and at road sections in 2015-2019, disaggregated for transport mode and location in or outside the urban area. Of 7% of fatal crashes at intersections it is unknown whether they occurred in or outside the urban area. Moreover, an actual 15% of road deaths remain unregistered. For these, location data are unavailable, not even whether the crash occurred at an intersection or road section[4].

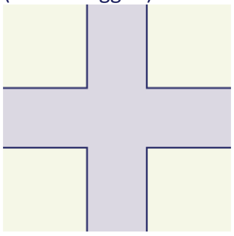
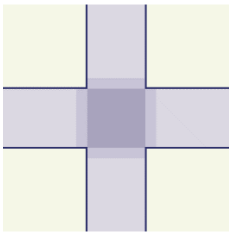
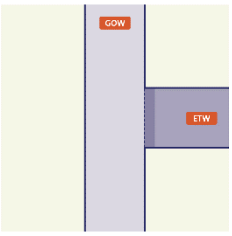
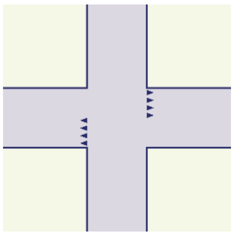
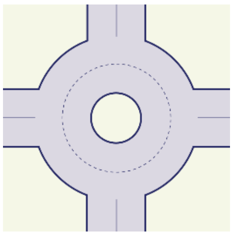
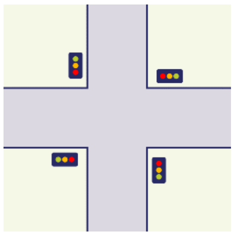
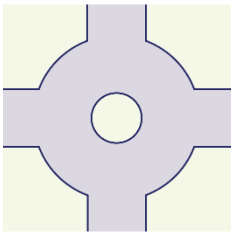
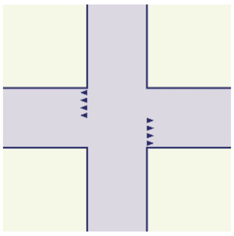
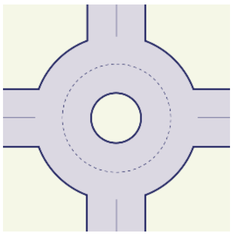
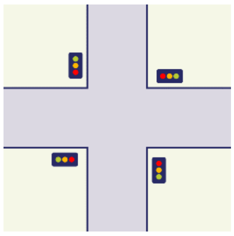
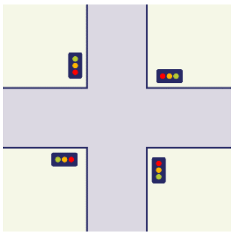
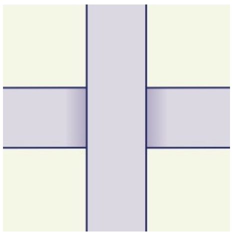
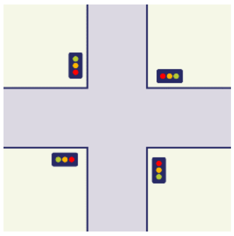
	Total 2015 – 2019 averages				In the urban area				Outside the urban area			
	Intersection		Road section		Intersection		Road section		Intersection		Road section	
	#	%	#	%	#	%	#	%	#	%	#	%
Total	**175**	**31%**	**382**	**69%**	**99**	**48%**	**109**	**52%**	**64**	**22%**	**233**	**78%**
Pedestrian	14	26%	39	74%	12	36%	21	64%	1	7%	13	93%
Bicycle	76	54%	64	46%	49	60%	33	40%	24	49%	25	51%
(light) Moped	15	42%	21	58%	10	50%	10	50%	4	31%	9	69%
Motorcycle/scooter	12	27%	33	73%	5	36%	9	64%	6	21%	23	79%
Car	42	19%	183	81%	13	33%	26	67%	26	16%	138	84%
Truck and delivery van	3	11%	25	89%	1	33%	2	67%	2	9%	21	91%
Other	12	43%	16	57%	8	50%	8	50%	3	38%	5	63%

4 What is the ideal intersection according to Sustainable Safety?

According to Sustainable Safety, the ideal intersection depends on the road categories of the intersecting roads. For more information about Sustainable Safety, see SWOV fact sheet *Sustainable Road Safety*. *Table 3* indicates which intersection is recommended at which location. The recommended intersections are presented in order of safety, from most recommended to least recommended. An additional note: At 50-50/50-70/70-70 (distributor-distributor road) intersections, safety depends on the capacity of the intersection. Intersection capacity in its turn depends on the number of lanes on the legs and the traffic distribution across the legs. The table is based on the assumption that each intersection has the same traffic volume. However, because a priority intersection has a lower capacity, it cannot cope well with a large amount of traffic when demand is high. For busy intersections, a signalised priority intersection is therefore safer. The section under the question *Which intersection types are safest?* explains why one intersection type is safer than the other.

4. We do not know whether the unregistered road deaths more often occurred on road sections or at intersections; this may lead to a distorted picture of crash distribution when using only the BRON-registered data. Underreporting is highest among cyclists, who generally crash at intersections more often. Bicycle-only crashes, however, that are even less registered, more often occur on road sections.

*Table 3. Recommended intersection types. The safest and therefore preferred type is mentioned first.*In the figure GOW stand for distributor road and ETW for access road.*

Intersection of	IN THE URBAN AREA Recommended intersection		Intersection of	OUTSIDE THE URBAN AREA Recommended intersection	
30-30 (access road-access road)	Unprioritised intersection (3- or 4-legged) 		60-60 (access road-access road)	Unprioritised intersection with a central elevation 	
30-50 (access road-distributor road)	Intersection wirh exit construction 	Priority intersection 	60-80 (access road-distributor road)	Multiple-lane roundabout 	Signalised priority intersection 
50-50/ 50-70/ 70-70 (distributor road-distributor road)*	One-lane or multiple-lane roundabout 	Priority intersection 	80-80 (distributor road-distributor road)	Multiple-lane roundabout 	Signalised priority intersection 
	Signalised priority intersection 		80-100 (distributor road-through road)**	Split-level crossing 	Signalised priority intersection 

* The indicated order is based on comparable traffic intensities
** Although this fact sheet only concerns at-grade intersections, a split-level crossing is included here, since it is the preferred option for these road types

The guiding principle for sustainably safe intersections is that conflicts between vehicles may and can only occur when vehicle speed and mass do not strongly diverge [9]. For the sake of road safety, traffic calming measures near or on intersections are therefore required. At intersections with distributor roads in the urban area, where motorised traffic meets, a maximum speed of 50 km/h is considered safe. In situations where heavy motorised traffic intersects with the much lighter (light) mopeds and bicycles or with pedestrians, speed should be reduced even more. For example, for intersections with distributor roads in the urban area where pedestrians and cyclists intersect with motorised traffic, the safe maximum speed is 30km/h [9]. Lower speeds can be enforced by roundabouts, speed humps just before the intersection, or a raised junction. In addition, sustainably safe intersection requirements are intended to exclude certain combinations of crash opponents (for example trucks and bicycles) being involved in conflicts in certain circumstances, since the implemented traffic facility virtually excludes these encounters [9]. For the purpose of sustainable safety, the following intersection facilities are therefore recommended (*Table 4*):

Table 4. Main intersection facilities to prevent common conflicts or collisions. For a more detailed description of the conflict types, see the section What characteristics affect intersection safety? And for information on deflection of the bicycle track and the bike box, see the section How to make intersections safer for cyclists?.

Conflict	**Conflict or crash opponent**		
	Motor vehicles with each other	**Pedestrians, bicycles and mopeds with each other**	**Cars or trucks versus pedestrian, bicycle or moped**
Converging or diverging conflicts	Roundabout	-	Paths/tracks and 50km/h roads: deflection of the bicycle track At traffic lights: bike box
Lateral conflicts	Roundabout or speed hump	Speed hump	Roundabout or speed hump
Frontal conflicts, with turns	Dedicated turning lane for left turns (not at roundabouts)	-	Median

In practice, the choice of facility often depends on aspects other than road safety. For example, traffic volume, available space and costs.

5 Which intersection types are safest?

Research [9] shows that roundabouts are the safest intersections. The list of intersection types below is in order of safety, from safest to least safe[5]:

1. *Roundabout*. According to research comparing the crash risks of different types intersections [9], roundabouts are safer than conventional intersections. A recent publication [10], however, came to the contrary conclusion that more traffic injuries occur at roundabouts than conventional intersections. It is not clear to what degree this recent result is influenced by the fact that relatively unsafe intersections are more likely to be converted into a

5. Unprioritized intersections, and therefore right of way for traffic coming from the right, are not included in the list because they belong to a different scope, viz. residential areas (30 and 60 km/h zones). They can therefore not be compared to the intersections in this list.

roundabout than relatively safe intersections. Before-and-after studies conducted at the same locations [11] [12], have shown that the conversion of an intersection into a roundabout lead to a substantial reduction in traffic casualties.
2. *Prioritised intersection*. Traffic volumes at these intersections are often lower than at signalised intersections. The design of a priority intersection is simpler than that of a signalised intersection. This results in less complex situations and, thus, fewer crashes.
3. *Signalised intersection*. These intersections are generally less safe than other types of intersections. The choice for a signalised intersection is often made when other intersection types would not be able to handle the high number of passing motor vehicles. Signalised intersections are often complex because of their higher capacity, which may reduce their safety. The capacity of an intersection is determined by the number of lanes of the legs and by traffic distribution across these legs.

Furthermore, a new intersection has recently been introduced: the bow-legged intersection (for a description, see the section *What are the different types of intersection?*). It is, however, still too early to include the bow-legged intersection in the list above, since bow-legged intersections have not yet sufficiently been evaluated. There are, however, some graduate studies of bow-legged intersections. They generally conclude that a bow-legged intersection has more points of conflict than a single-lane roundabout. The points of conflict are, however, further apart than at priority intersections, the types of conflict are different than at other intersection types and conflicts occur at lower speeds.

For more information about the safety of bow-legged intersections, see the following three graduate studies: [13] [14] [15].

6 What are the requirements for the design of intersections?

There are no legal requirements for the design of different types of intersection. Sustainable Safety does, however, include recommendations (for a description, see the section *What is the ideal intersection according to Sustainable Safety?*) and CROW also makes several design recommendations:

- Basic characteristics intersections and roundabouts (CROW) – Design recommendations for intersections in and outside the urban area [1]
- Road Design Manual (CROW) – Design recommendation for intersections in and outside the urban area [8]
- ASVV (CROW) – Design recommendations for intersections in the urban area [7]

Since there are no legal requirements for the layout of intersections (nor the layout of road sections), uniformity is not guaranteed. Guidelines are easier to circumvent than legal requirements. This is as it should be, since the situation is different everywhere and therefore a similar design for every intersection would be impossible. Furthermore, the space available for the intersection and the environmental characteristics also come into play. They affect what an intersection will look like in a given situation.

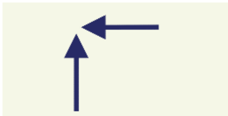
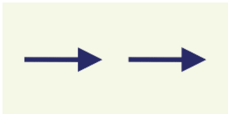
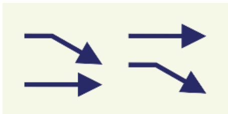
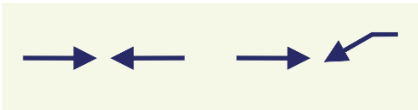
7 What characteristics affect intersection safety?

The first determining characteristic for intersection safety is the type of intersection. Signalised intersections, for example, are less safe than other intersection types because of their capacity, high traffic volumes and complexity (also see the section *Which intersection types are safest?*). Moreover, each intersection type has characteristics that may affect its safety:

- the number of possible points of conflict;
- speed;
- differences in mass of vehicles that meet at the intersection;
- impact angle;
- the amount of traffic, broken down by the number of passing motor vehicles and the ratio between main flow and lateral flow.

Intersection safety strongly depends on the number of possible points of conflict: the fewer, the safer. A conflict between vehicles should only be possible when speed and mass differences are small. The impact angle is another important factor. The angle is determined by the type of conflict. *Table 5* shows four different conflict groups.

Table 5. Four conflict groups [9].

Conflict group	Description	Illustration
Lateral conflicts	Vehicles at perpendicular angles	
Rear-end conflicts	Vehicles driving in same direction	
Converging or diverging conflicts	Vehicles starting or ending up in same direction (merging or exiting)	
Frontal conflicts	Oncoming vehicles	

A last important characteristic is the traffic volume: the more passing vehicles, the more crashes. The way in which this contributes to intersection safety was studied in two ways. For the urban area, the number of passing vehicles was studied [9]. This is the sum of lateral flows and main flow. For intersections outside the urban area, the ratio between lateral-flow volume and main-flow volume was studied. This ratio is strongly related to the number of injury crashes [16].[6]

6. This is based on existing knowledge that was investigated in this way. The number of passing motor vehicles was only studied for the urban area, and the ratio between lateral flows and main flow was only studied for intersections outside the urban area. Both traffic volume and distribution are, however, relevant to road safety both in and outside the urban area.

For a comprehensive description of the characteristics that affect intersection safety, see SWOV report *Several aspects of intersection safety*.

8 Do traffic lights make intersections safer?

Before-and-after studies show that intersections become safer after implementation of traffic lights [17] [18]. However, when the number of injury crashes at signalised intersections is compared to this number at other intersection types with similar traffic volumes, signalised intersections are the least safe intersection type. Unsignalised intersections and roundabouts have fewer injury crashes [9] [19]. So, after adjusting for traffic flow to determine risk, signalised intersections are still less safe.

In addition: traffic lights are often used when the number of passing motor vehicles is too high for other intersection types to cope with. They enhance traffic flow.

9 Why are roundabouts preferable to other intersection types?

Roundabouts are the safest intersection type because of the following three characteristics:

- They have fewer points of conflict (see *Figure 1*);
- Speed is reduced, especially when the legs have perpendicular connections to the roundabout;
- The impact angle is smaller.

In terms of road safety, roundabouts should therefore be preferred to other types of intersection. First, single-lane, four-legged roundabouts only have 4 conflict points, compared to the 24 conflict points of ordinary four-legged intersections [9]. This difference is easy to spot when looking at *Figure 1* below. The median island ensures fewer conflicts, since motorised traffic can only flow in one direction. This makes a roundabout less complex than other types of intersection.

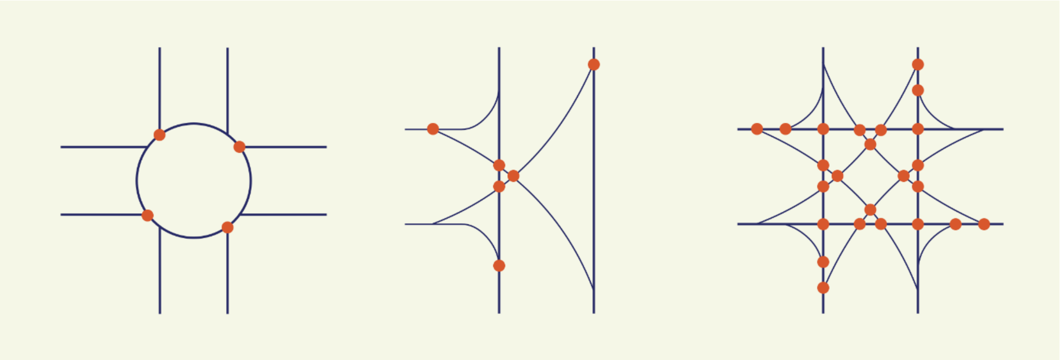


Figure 1. The differences in conflict points between roundabouts, three-legged and four-legged intersections.

Second, because of the layout and priority regulation of roundabouts, all traffic flows need to reduce speed, whereas this is not the case at many other types of intersection [20]. The median island ensures that road users cannot cross in a straight line. Together with the perpendicular location of the legs, this has a speed reducing effect. There are roundabouts with deflecting legs or multiple lanes; they have a lesser speed reducing effect. The priority regulation reduces speed since road users intending to enter the roundabout have to give right of way to traffic already on the roundabout. Third, the layout of a roundabout makes for an entry angle that is smaller than that of other intersection types, which also diminishes the impact angle. Certain conflict types therefore no longer occur on roundabouts [21]. On a roundabout, there are more lateral conflicts which are relatively less serious, whereas at other intersection types, frontal conflicts, that are often relatively serious, may also occur.

10 How safe are the different kinds of roundabout?

The list below describes the safety of single-lane roundabouts, multiple-lane roundabouts, and turbo roundabouts:

- *Single-lane roundabout*. Four-legged, single-lane roundabouts are safer than four-legged intersections. Their safety is due to the lower number of conflict points, speed restriction for all traffic flows and the difference in entry and impact angles [9].
- *Multi-lane roundabouts*. These are less safe than single-lane roundabouts, but still safer than other types of intersections [22]. Multi-lane roundabouts are less safe because they have a larger number of conflict points, they are more complex, driving speed is higher, and they have a less sharp entry angle [23].
- *Turbo roundabouts (with or without raised lane separators).* The road safety effect of turbo roundabouts is almost identical to that of single-lane roundabouts, provided the data are corrected for traffic volume [9]. Converting conventional intersections to single-lane roundabouts (68,1% - 78,7% crash rate reduction) and to turbo roundabouts (76,1% crash rate reduction) generates almost equal road safety benefits [23] [24].

11 How safe are intersections to cyclists?

In the urban area, an average 60% of cyclist fatalities occur at intersections, and outside the urban area an average of 49% (in 2015-2019). For cyclists, conventional intersections are generally less safe than roundabouts (also see the section *How safe are roundabouts to cyclists?*). Intersections with separate bicycle facilities are safer than intersections without these facilities (for an overview of bicycle facilities at intersections, see the section *How to make intersections safer for cyclists?*).

A second factor contributing to cyclist safety at intersections is the blind spot of (particularly) trucks. Most blind spot crashes are 'classical': a truck turning right and a cyclist going straight ahead. Most blind spot crashes occur in the urban area, and especially when the cyclist was riding on a bicycle track [25]. Most of these crashes occur at bicycle tracks at a distance of less than one metre from the carriageway. Half of the blind spot crashes occur at signalised intersections.

12 How to make intersections safer for cyclists?

Several intersection facilities may enhance cycling safety. These are the most important ones:

- *Median island*. Median islands make crossing safer for cyclists, because they can cross in stages. This is most relevant at wide and busy distributor roads in the urban area [26].
- *Bike box*. Bike boxes at traffic lights allow cyclists to position themselves ahead of other traffic, so that they can turn left more safely and easily. They are more visible to motorised traffic since there are no blind spots. That is why bike boxes can prevent blind spot crashes [25] [27].
- *Deflecting the bicycle track inwards or outwards*. Just before or after an intersection, the bicycle track deflects from or towards the carriageway [25]. This enhances cyclists' visibility to other traffic. For cyclists on urban distributor roads, the probability of crash on an intersection with an access road is lowest on roads with a one-way bicycle track that is at a distance of two to five meters to the carriageway [26] [27]. A larger distance actually results in a crash increase, although this increase is smaller than in the case of bicycle lanes. For intersections between two distributor roads, the effects of inwards and outwards deflection of the bicycle track and the optimal distance between intersection and bicycle track are unknown.
- *Separate green phase for cyclists*. Traffic lights at intersections with a separate green phase for cyclists enhance road safety [18]. This implies that green lights for cyclists coincide with red lights for motor vehicles. Thus, no conflicts between these transport modes would occur if nobody ran a red light.

Which of the facilities above is chosen depends on the volume of passing traffic and on the presence of bicycle facilities on the connecting road sections.

13 How safe are roundabouts to cyclists?

For cyclists, roundabouts are generally much safer than other types of intersection. In the Netherlands, from the 1980s onwards, a lot of intersections were converted to roundabouts, with or without separate bicycle facilities. The effects on (light) moped rider and cyclist safety were also researched at that time. The research showed that conversion of an ordinary intersection to a roundabout resulted in a 60% decrease of casualties among (light) moped riders and cyclists, after correction for the general downward trend in casualty numbers [12].[7] More recent research in Belgium and Denmark shows that, in those countries, the conversion from intersections to roundabouts is less favourable to the number of (serious) injury crashes among cyclists [28] [29]. These studies are, however, hard to compare to the Dutch studies. For example, the number of cyclists, in Belgium in particular, is lower than in the Netherlands, and speed at Danish roundabouts is less restricted by road design than it is at Dutch roundabouts. Thus, it is unlikely that Belgian and Danish results also apply to the Dutch situation.

In the Netherlands, after the conversion of intersections to roundabouts, increases in cyclist safety differ between roundabouts. The size of the crash reduction depends on the bicycle facility chosen. *Table 6* shows the effects on the number of (light) moped and bicycle crashes after the conversion. The table compares bicycle facilities in the old situation (intersection) and the new situation (roundabout). The table shows that implementing bicycle tracks at roundabouts decreases the number of (light) moped and bicycle crashes most (89-100% fewer crashes than at the old intersections). In addition, removing bicycle tracks from the old situation (intersection) has the least effect (13-39% fewer crashes at the roundabout) [30]. Moreover, at roundabouts, fewer blind spot crashes occur than at intersections. Only 11% of all blind spot crashes in 2002-2006 occurred at a roundabout [25].

Table 6. Effect of converting an intersection to a roundabout on number of moped and bicycle crashes [30].

Bicycle facility at intersection (before)	Bicycle facility at roundabout (after)	% reduction of moped and bicycle crashes	Number of locations studied
Intersection without bicycle facility	Roundabout without bicycle facility	50%	15
	Roundabout with bicycle lane	54%	35
	Roundabout with bicycle track	100%	8
Intersection with bicycle lane	Roundabout with bicycle lane	31%	20
Intersection with bicycle track	Roundabout without bicycle facility	13%	3
	Roundabout with bicycle lane	39%	48
	Roundabout with bicycle track	89%	49
Total		55%	178

7. In the reference cited, no distinction was made between moped riders, light moped riders and cyclists, because they all used the bicycle track at the time of the study. That is why their data are aggregated. This also goes for table 6 and the explanation of the table.

Cross-comparing roundabouts for the number of cyclist fatalities, roundabouts with bicycle tracks prove to be safer than roundabouts without bicycle facilities and roundabouts with bicycle lanes, and roundabouts without bicycle facilities have fewer cyclist fatalities than roundabouts with bicycle lanes [12] [31] [32]. These results are also apparent from foreign studies [28] [29] [33].

Based on a recent publication [10] in which registered traffic casualties at roundabouts were analysed, it has been claimed that roundabouts are less safe for cyclists than previously believed [34]. Additionally, in a recent masters thesis [35] comparing the crash risk for cyclists on 7 roundabouts in Haarlem to the risks on the city's other intersection types, the bicycle crash risk was unexpectedly found to be highest for roundabouts. Based on these two studies, however, it is too early to conclude that roundabouts are less safe for cyclists. As discussed in the masters thesis, the small sample size of roundabouts is not sufficiently representative for all roundabouts in the Netherlands. In the other study analysing traffic casualties on all roundabouts, no correction was made for cyclist volumes. At intersections with more cyclists there are, with a constant crash risk, more bicycle crashes. A big advantage of before-and-after studies, such as in *Table 6*, is that they can correct for these possible differences.

For more information about cyclist safety, see SWOV fact sheet *Cyclists*.

14 Is priority for cyclists on roundabouts safer than no priority?

Several SWOV reports and a DTV Consultants memo show that the safety benefits of a roundabout are greater when cyclists at bicycle tracks are not given right of way [12] [30] [31] [32]. In 2002, Dijkstra [12] calculated an estimated annual reduction of 52 to 73 inpatients[8], if cyclists were not given right of way at any roundabout with bicycle tracks. An additional factor is that roundabouts are the safest intersection type for cyclists anyway (also see the section *How safe are roundabouts to cyclists?*).

Cyclists not having right of way implies that they should yield to motor vehicles on the legs of the roundabouts, cyclists having right of way implies that motor vehicles should yield to cyclists. In general, roundabouts are very safe intersections to cyclists (whether or not having right of way). There are two possible reasons why roundabouts with cyclist priority are less safe [12]. First, drivers could wrongly think they automatically have right of way over cyclists. Second, drivers wanting to enter a roundabout are focused on motorised traffic already on the roundabout, and they have a hard time needing to give right of way to cyclists on a bicycle track as well. Drivers would need to make (too) many observations in a short time, which would facilitate the overlooking of cyclists. Considering cyclist vulnerability in a crash with a motor vehicle (or the great difference in mass between cyclists and motor vehicles), this crash type often has serious consequences, for cyclists in particular.

Despite the conclusion that, on roundabouts with bicycle tracks, cyclists not having right of way are safer than cyclists who do, CROW recommends to create cyclist priority on these

8. At the time of this study, the term inpatients was normally used in the Netherlands. From 2010 however, this term was abandoned as not all inpatients (as registered in BRON) proved to have been hospitalised or seriously injured.

roundabouts in the urban area, but not outside the urban area [36]. This guideline is based on balancing safety, comfort and cyclist traffic flow.

15 How safe are intersections to pedestrians?

In 2015-2019 an average 26% of fatal pedestrian crashes occurred at intersections. They can be subdivided into crash locations: 36% occurred in the urban area and 7% outside the urban area. The pedestrian share is almost half that of the average share of cyclists in fatal intersection crashes (54%) in that same period. This is also shown by Table 2 at the section *How many casualties are due to crashes at intersections?*

The degree of pedestrian safety at intersections depends on i.a. the intersection type, presence or absence of traffic lights and zebra crossings.

Intersection type

In general, roundabouts are safer for cyclists than conventional intersections and signalised intersections [37]. This is due to the speed reducing effect of a roundabout, simpler conflicts, and minimum conflict space [37]. As a rule, one-lane roundabouts are safer than multi-lane roundabouts [38]. Furthermore, several international studies show that pedestrians have a relatively higher crash rate, with a more severe outcome, at four-legged than at three-legged intersections [39]. Thus, the pedestrian risk of a fatal crash or serious injury crash is 10% higher at four-legged intersections than at three-legged intersections [40].

Signalised intersections

For pedestrians, signalised intersections are often safer than unsignalised intersections. At signalised intersections, there are fewer conflicts between pedestrians and motorised traffic due to time separation. [41]. It should, however, be noted that at signalised intersections motor vehicles may be less inclined to reduce speed during the green phase, which may be more dangerous for pedestrians that start crossing at a later time during the green phase, which implies they partly cross during the red phase. Moreover, motor vehicles running red lights remains a major concern for pedestrians. Conversely, unsignalised intersections force motor vehicles to reduce their speed, since they need to be more careful.

Signalised intersection are, however, safer than intersections with only zebra crossings (see the next subheading) [41]. In addition, pedestrian green phases are sometimes (too) short or coincide with the green phase for turning motor vehicles. This leads to complex situations, particularly when a multi-carriageway road needs to be crossed [42]. In general, turning traffic at intersections (either signalised or unsignalised) is a concern for pedestrians, because they are often overlooked. At unsignalised intersections this is a greater concern, and more so in case of traffic turning left than in case of traffic turning right [42].

Zebra crossing

It is not unequivocal whether intersections with zebra crossings are safer than intersections without zebra crossings [41]. There are studies that claim that pedestrians are given priority by motor vehicles 30% to 40% more often than when zebra crossings are absent [43]. Other studies, on the other hand, do not find this effect [44]. A comparative study by Zegeer et al. [45], for example, found no decrease of pedestrian crashes for unsignalised intersections with zebra crossings. The studies even found an increase in pedestrian crashes when such intersections were passed by more than 12,000 vehicles a day. What needs to be noted is that these are American studies. Dutch zebra crossings may differ from American zebra crossings, e.g. because the latter often use continuous lines as a zebra crossing [42].

For more information about pedestrian safety, see SWOV fact sheet Pedestrians.

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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