Pedestrian and Bicycle-Friendly Roundabouts; Dilemma of Comfort and Safety

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Abstract

First to be addressed is the circulatory speed of motorized traffic on roundabouts. After all, for the safety of pedestrians and cyclists, the difference in speed between cars and bicycles at a conflict point is very important: a reduction in collision speed from 30 mph (48 km/h) to 20 mph (32 km/h) means that the risk of fatal injury is reduced from 45% to 15 or 5% (a factor of 3 or 9). The speed through roundabouts is determined by the vehicle path curvature. On single-lane roundabouts, an increase in the vehicle path curvature results in a reduction of vehicular accident exhibits. On multilane roundabouts, however, increasing the vehicle path curvature can result in a higher potential for sideswipe collisions. On double-lane roundabouts, designers are faced with a dilemma: accepting a higher number of sideswipe collisions involving motorized traffic (when they increase vehicle path curvature) or accepting serious accidents involving pedestrians and cyclists (when they decrease vehicle path curvature). The turbo-roundabout offers a solution to this dilemma. This kind of roundabout is based on important principles applying to single-lane roundabouts: 1) no weaving traffic on the roundabout and 2) dealing with conflict points by means of slow speeds.

Addressed second are the right-of-way regulations for cyclists and pedestrians in which cyclists are usually given priority in the Netherlands. But in the case of roundabouts, this leads to a situation in which either safety or convenience is diminished. In attempts to resolve this dilemma, Dutch guidelines (as stated in CROW publication 126) recommend that within built-up areas, cyclists on the cycle track going around the roundabout be given right-of-way (for convenience) but that outside of built-up areas (and when another design is applied), they should not be given right-of-way (for reasons of safety). Research findings are discussed. It is concluded that further research is needed to demonstrate the degree to which roundabouts that give cyclists the right-of-way decrease their safety, even when given the best roundabout design possible.

Finally, this contribution devotes attention to the designing of cycle crossings for crossing two double lanes. For pedestrians, a width of 3 metres of the splitter island (or reservation) is sufficient to anticipate motorized traffic satisfactorily. The conclusion is that the higher speed of the cyclists in comparison with that of pedestrians places additional demands on the geometric design for creating sufficient anticipation time (offered by a jog).

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1 BACKGROUND OF ROUNDABOUTS IN THE NETHERLANDS

1.1 Original rotary

Originally, rotaries in the Netherlands were based on three principles:
- Interactions between the various traffic streams entering, circulating and exiting the rotary were based on performing various weaving movements.
- For this reason, the connecting roadways intersected the rotary tangentially.
- Traffic coming from the right (traffic on the approach roadways) had the right-of-way.

For motorists, all this weaving was difficult and resulted in many collisions. And because the traffic on the rotary had to yield to the traffic entering from the various connecting roadways, the rotary quickly became congested during heavy traffic conditions. When this problem was countered by building rotaries with larger inscribed circle diameters motorists merely increased their speeds, and more serious accidents occurred. Especially Accidents involving pedestrians and cyclists were particularly bad.

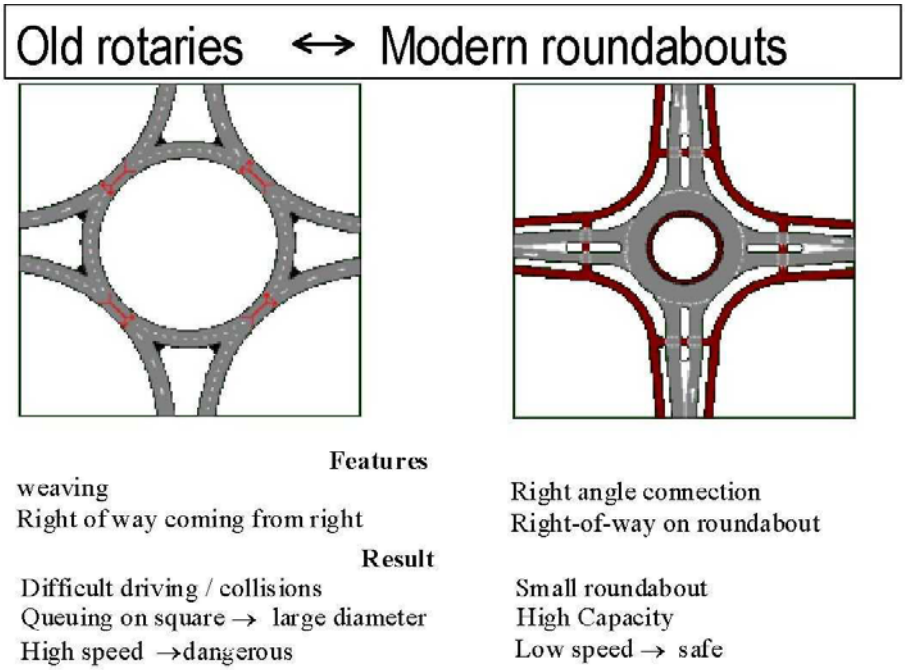


Exhibit 1 Rotary and roundabout

1.2 Modern roundabout

The main factors in which the modern roundabout differs from the original rotary in handling traffic are that:
- Interaction between the various traffic streams entering, circulating and exiting the roundabout is now based on low-speed.
- For this reason, the connecting roadways intersect the circulating roadways at a 90-degree angle.

- The traffic on the circulating roadway has the right-of-way.

This modern roundabout is being used more and more often in the Netherlands. Because the traffic on the circulating roadways has the right-of-way, it no longer has to delay. This means that the inscribed circle diameter of the roundabout can remain small, because of the absence of queues on the roundabout. Because the connecting roadways intersect the circulating roadways at 90-degree angles, conflict points between road users are clearly recognizable while speeds are slow. This means that a high processing capacity can be combined with safe traffic handling on a small surface. The modern single-lane roundabout has thus become a success and is an important instrument for making intersections sustainably safe. In the Province of South Holland, it has been possible to compare before and after situations involving 48 rural roundabouts. The annual number of casualty accidents has been reduced by approximately 80% [PZH, 2002]. The reduction in the number of moped rider and cyclist casualties on these roundabouts was about the same. So as to leave no doubt, these exhibits apply to rural single-lane roundabouts on which the moped riders and cyclists do not have the right-of-way.

2 SPEED

2.1 The importance of 90-degree connecting roadways and traversable aprons for speed reduction

Speed reduction is one of the most important factors in the success of the Dutch roundabout. To achieve this success, the Dutch roundabout is characterized by three points:

a. 90-degree connecting roadways
b. Traversable apron around the central island
c. A small inscribed circle diameter.

In reference to point a: 90-degree connecting roadways instead of tangentially. This applies not only to the urban single-lane roundabouts but also to the rural single-lane roundabouts. This measure reduces the speed of passenger cars to approximately 35 km/h (20 mph). As to capacity, by using research data collected from other countries as well as from the Netherlands, it is possible to compare the capacities of the roundabouts and to show that applying this measure has little if any impact (maximum sum entry flow and circulatory flow = approx. 1550 vehicles/hour).

Obviously, for rural single-lane roundabouts, the Dutch guideline regarding the speed reduction to be obtained (maximum speed of approx. 35 km/h or 20 mph) differs from the recommendations in the FHWA (U.S. Federal Highway Administration) guideline (maximum speed of approx. 40 km/h = 25 mph). And for the rural double-lane roundabouts, the difference between the recommendations is even greater.

In reference to point b: To make these roundabouts traversable for trucks as well, a slightly elevated traversable apron is installed around the central island so that trucks can traverse it at low speed. The vehicle path curvature for passenger cars is kept to a maximum.

In reference to point c: By using a traversable apron, the inscribed circle diameter for rural single-lane roundabouts can also be kept relatively small.

2.2 The importance of speed reduction for the safety of slow traffic

Research [Ashton and Mackay, 1979] has shown that there is a high correlation between collision speed and the risk of fatal injury. The risk of death for occupants of passenger cars is 20 times greater when the collision speed is 80 km/h than when it is 30 km/h. This correlation is particularly important for the more vulnerable road users: at a collision speed of 20 mph (32 km/h), 5% of the pedestrians will be killed, 45% of pedestrians will be killed when this speed is 30 mph (48 km/h), and 85% of the pedestrians will suffer a fatal accident if struck by a vehicle travelling at 40 mph (64 km/h) 85%. [SWOV: Policy Information System for Road Safety, 1998]. Exhibit 2 shows a reduction of the chance of death with a factor 3, by reducing the collision speed from 30 mph to 20 mph [UK, 1995] and [FHWA, 2000].

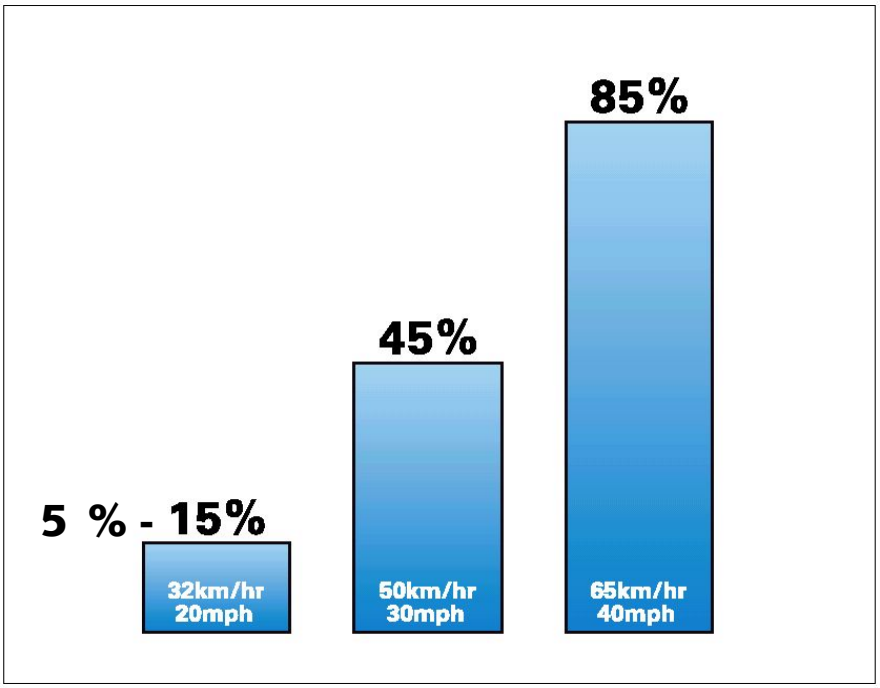


Exhibit 2 Pedestrian's chances of death if hit by a motor vehicle (FHWA-RD Exhibit 2-2)

Never the less, the exhibit shows that reduction of speeds through the roundabout is very important for the safety of pedestrians and cyclists.

2.3 The dilemma of speed reduction and path overlap on double-lane roundabouts

According to "Roundabouts: An Informational Guide" [FHWA, 2000] (as quoted in the section entitled “Design Speeds, subsection 6.2.1.2), "International studies have shown that increasing the vehicle path curvature decreases the relative speed between entering and circulating vehicles and thus usually results in decreases in the entering-circulating and exiting-circulating vehicle crash rates. However, at multilane roundabouts, increasing vehicle path curvature creates greater side friction between adjacent traffic streams and can result in more vehicles cutting across lanes and higher potential for sideswipe collisions" [FHWA, 2000 and QDRM, 1999].

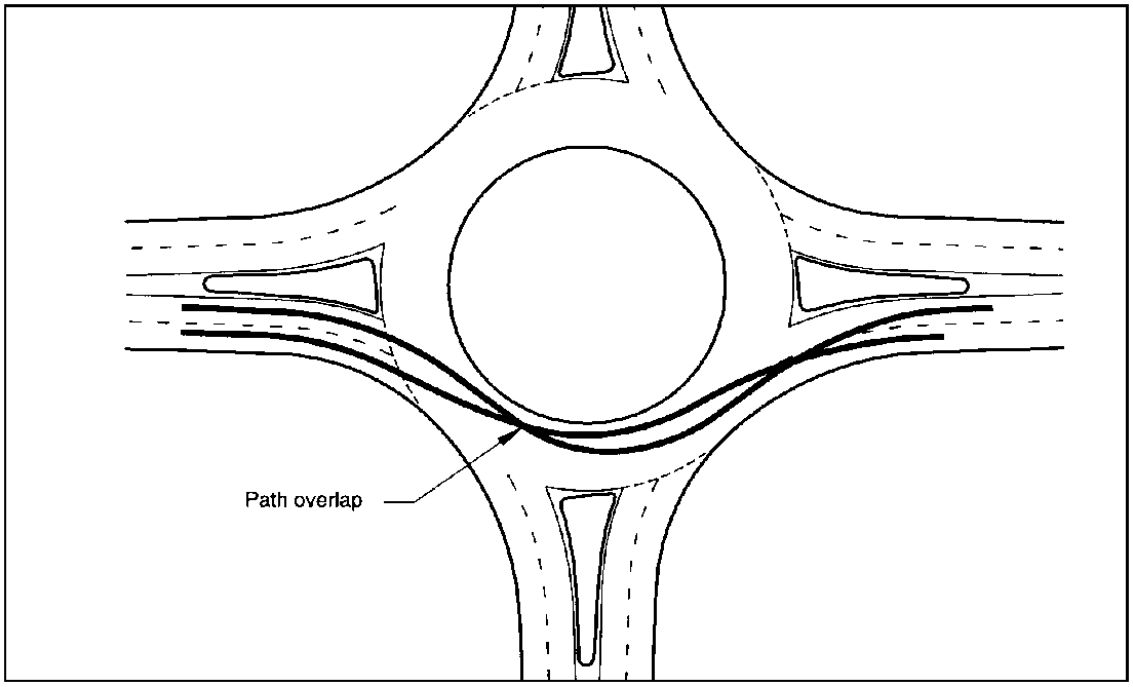


Exhibit 3 Path overlap at a double-lane roundabout (FHWA-RD Exhibit 6-45)

In combination with pedestrians and cyclists crossing the road, this produces a dilemma for designers.

2.4 The development of the turbo-roundabout

In the Netherlands, the author has in 1996 developed a new kind of multilane roundabout: "the turbo-roundabout". This kind of roundabout is based on important principles applying to single-lane roundabouts:

1. no weaving traffic on the roundabout and
2. dealing with conflict points by means of slow speeds.

As mentioned previously, the traffic circle was originally based on a concept that used several lanes between which the various streams of traffic could weave in and out. This developed into the traffic square with concentric marking. It was learned from actual situations, however, that not all road users appreciated having to weave. In addition, this method of handling traffic led to congestion. In the next attempts to resolve this problem, traffic squares were increasingly marked with spiral lane marking, particularly those rotaries equipped with traffic lights. On these squares, weaving is no longer necessary. Traffic squares with spiral lane marking have since become the norm, if supplied with traffic lights.

The turbo-roundabout combines the characteristics of the modern single-lane roundabout with those of the traffic square with spiral lane marking:

- double lanes and at least one exit lane with two lanes (but there could also be four) *(to promote capacity)*
- spiral lane marking on the roundabout to eliminate weaving while circulating *(to promote safety)*
- no more than two lanes on the roundabout to which the traffic entering from an entry roadway must yield the right-of-way *(to promote safety)*

- low speeds *(to promote safety)*.

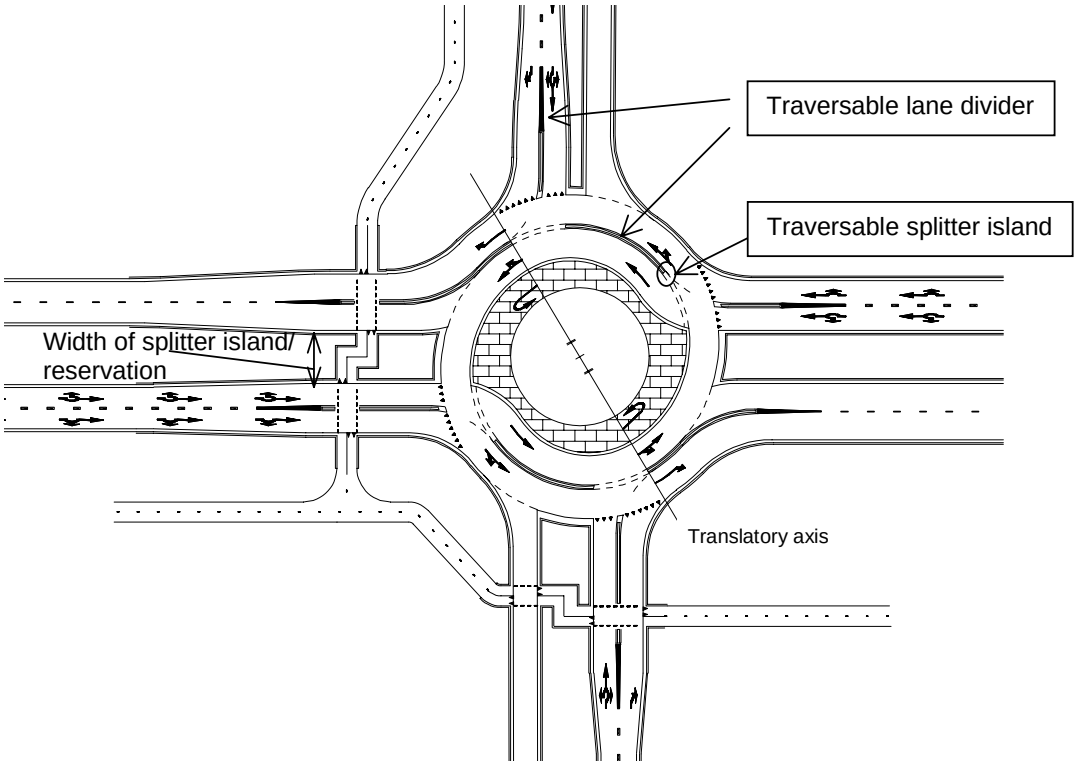


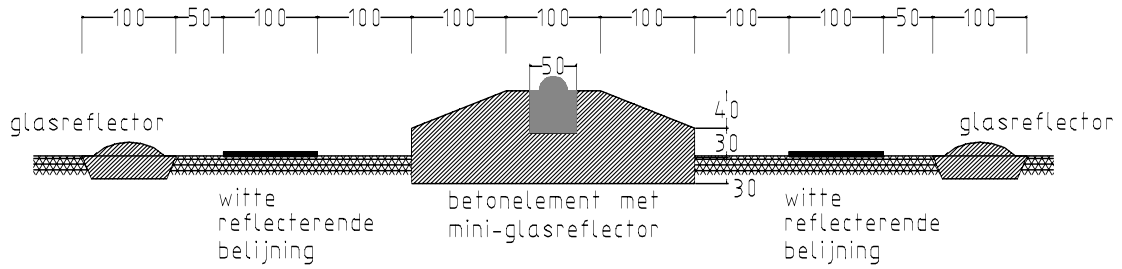
Exhibit 4 Turbo-roundabout

Because the translatory axis (along which the midpoint varies) is an important factor in designing a turbo-circuit, it is indicated here as well. The translatory axis must be positioned in such a way that traffic approaching the roundabout is not led into a circulating roadway with a small radius that then changes to one with a larger radius almost immediately.

This design:
- eliminates the necessity to weave
- reduces the number of potential conflict points from 16 to 10 in a design that is appropriate in terms of capacity to situations exhibiting major differences between the volumes on the connecting roadways.

(For more details about this design, please refer to Fortuijn and Carton, 2000 or visit www.pzh.nl).

Since weaving on the roundabout is no longer necessary, the divider between the lanes can be slightly elevated. Such a traversable lane divider directs traffic better, both when it is approaching and circulating through the roundabout. The traffic is induced to keep its own lane, and this helps to prevent sideswipe collisions that can occur not only upon entering the roundabout but also when exiting it.

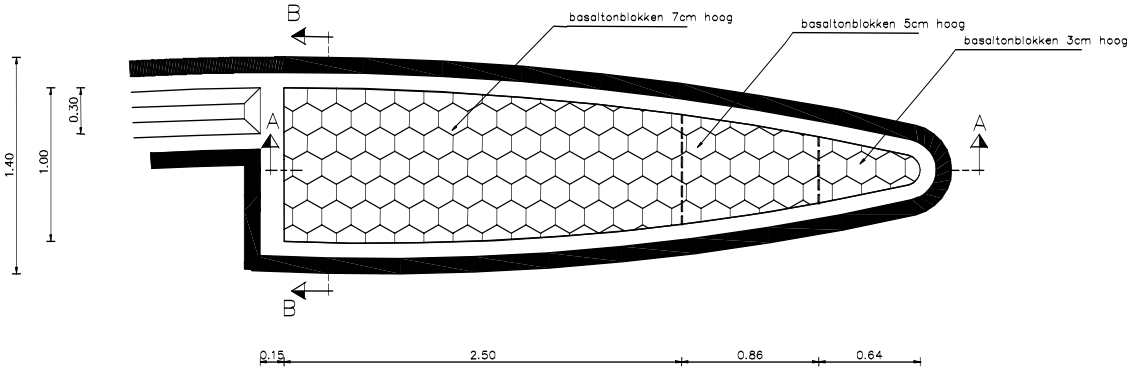


glass reflector / white reflective lane marking / concrete element with mini glass reflector / white reflective lane marking / glass reflector
Measures in mm

Exhibit 5 Section showing traversable lane divider

The traversable lane divider becomes evident even on the entry lane. From that point on, this divider keeps the motorist on course. Just before the connecting roadway enters the roundabout, the traversable lane divider can be curved a little to the right to keep the motorist in the approach roadway's right lane from seeing the innermost roundabout lane straight ahead.

On the roundabout, the traversable lane divider is introduced by a traversable splitter island. Not only does this act to guide the motorist while circulating through the roundabout but it also guides the traffic in the right lane of the approach roadway by visually screening off the opening to the innermost roundabout lane.



Translation: basaltonblokken 7 cm hoog = basalt blocks (elevation +7 cm.) etc.

Exhibit 6 Detail of traversable splitter island that introduces the traversable lane divider on the roundabout

Effective signposting and lane marking assists drivers in their choice of lanes before they enter the roundabout itself.

The turbo-roundabout design provides the conditions to achieve the following on double-lane roundabouts simultaneously:

- A low circulating speed to promote pedestrian and cyclist safety
- The minimizing of the risk of sideswipe collisions

Exhibit 7 Directional arrows with traversable lane dividers

About 15 of these roundabouts have been built in the Netherlands over the last three years. This article does not address the other design aspects of turbo-roundabouts.

Exhibit 8 Traversable lane divider with pedestrian and bicycle crossing

Exhibit 9 Traversable lane divider with truck

2.5 Table comparing dimensions recommended by FHWA and Dutch guidelines

Table 1 provides a listing of the design dimensions used for the various types of roundabouts with their circulating speeds.

Table 1 List of dimensions for roundabouts

	Site Category	Inscribed circle diameter	Inner radius of circulatory roadway	Traversable apron	Speed
FHWA	Urban Single-Lane*	30 to 40 m	9.5 to 14.5m	?	35 km/h (20 mph)
	Rural Single-Lane	35 to 40 m	11.5 to 14.5 m	?	40 km/h (25 mph)
	Urban Double-Lane	45 to 55 m	13.5 to 18.5 m	–	40 km/h (25 mph)
	Rural Double-Lane	55 to 60 m	18.5 to 21.5 m	–	50 km/h (30 mph)
CROW	Urban Single-Lane*	32 m	10.50 m	1.50 m to 4 m	36 km/h
	Rural Single-Lane*	36 m	12.75 m	3.00 m to 4 m	36 km/h
PZH	Rural Single-Lane*	37.40 m	13.50 m	4 m**	36 –38 km/h***
	Turbo (Double-Lane)*	50.20 m	12.00 m****	4 m**	37 - 39 km/h***

FHWA: Roundabouts: An Informational Guide
CROW: *Eenheid in rotondes* (Uniformity in roundabouts), a guideline used in the Netherlands
PZH: dimensions generally used by the Province of South Holland, The Netherlands (a region with a high volume of tractor-trailer traffic)
* 90-degree entry angle
** 4 m traversable apron → truck-friendly
speed (35 km/h) → bicycle-friendly roundabout
*** the speed within this range depends on the width (3 to 7 m) of the splitter island
**** the distance between the centres (5.3 m);
the inscribed diameter: 5.30 + 2 x (12 + 5.35 + .3 + 4.80) = 50.20 m

2.6 Conclusions on speed through roundabouts

It is known that collision speeds faster than 35 km/h (20 mph) are extremely hazardous for slow traffic: a pedestrian's chance of death if hit by a motor vehicle increases from 5% [SWOV, 1998] or 15% [FHWA 2000, page 25] to 45% (a factor between 3 and 9) when the collision speed increases from 35 km/h (20 mph) to 50 km/h (30 mph).

On single-lane roundabouts, all aspects of safety improve when the maximum vehicle path curvature is used. On double-lane roundabouts, the designer is faced with a dilemma: if he reduces the severity of collisions with cyclists and pedestrians by increasing the vehicle path curvature he will increase the risk of sideswipe collisions. The turbo-roundabout offers a solution to this dilemma by making it possible to achieve a reasonably low design speed and by eliminating a number of conflict points.

3 RIGHT-OF-WAY AND GEOMETRIC DESIGN

3.1 CROW publication 126 (a design guide used in the Netherlands): "Recommendations concerning bicycles"

CROW publication 126, *"Eenheid in rotondes"* (Uniformity in roundabouts), published in 1998, makes the following recommendation:

a within built-up areas: give cyclists right-of-way
b outside built-up areas: do not give cyclists right-of-way

Each of these right-of-way regimes requires its own design.
A solution involving having cyclists on the roadway is not included in the recommendations. Nevertheless, earlier research [SWOV, 1993] showed that at low volumes (fewer than 6000 cars/24 hours for all entries), there is no demonstrable difference in safety between roundabouts with and those without a cycle track. This means that a mini-roundabout in the

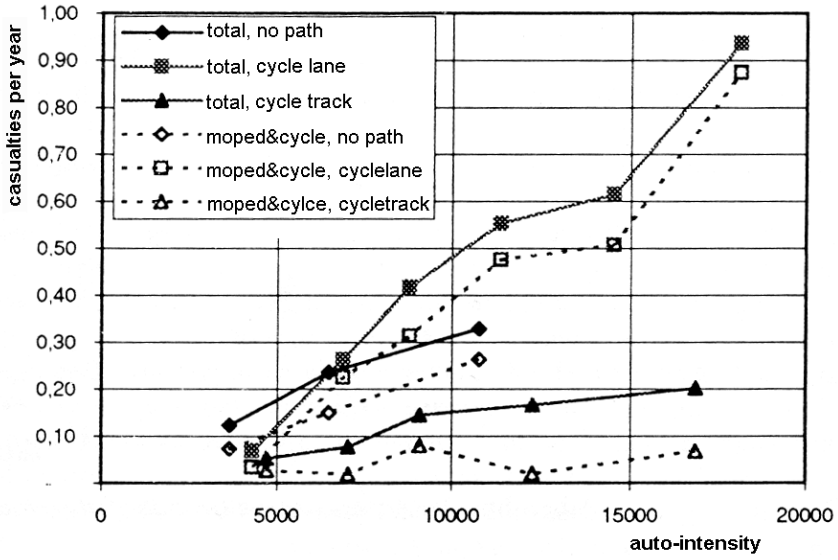


Exhibit 10 Number of casualties per bicycle facility (SWOV, 1995)

Dutch situation would also be quite defensible as long as the speed reduction of its motorized traffic would remain sufficient. This is not addressed in the Dutch guideline.

The recommendation to give cyclists right-of-way within built-up areas is not followed everywhere in the Netherlands. This is because safety research has shown that this solution weakens the cyclists' position. The critical aspect here is the anticipation time for motorists.

Exhibit 11 shows the recommended design for a roundabout on which the cyclists are given right-of-way. The cycle track runs parallel to the circulatory roadway at a distance of 5 metres. This means that the cycle track legally belongs to the same road as the circulatory roadway. And this distance of 5 metres is also very important for safety. Pedestrian crossings are also included in this design, with right-of-way given to the pedestrians by means of a zebra crossing.

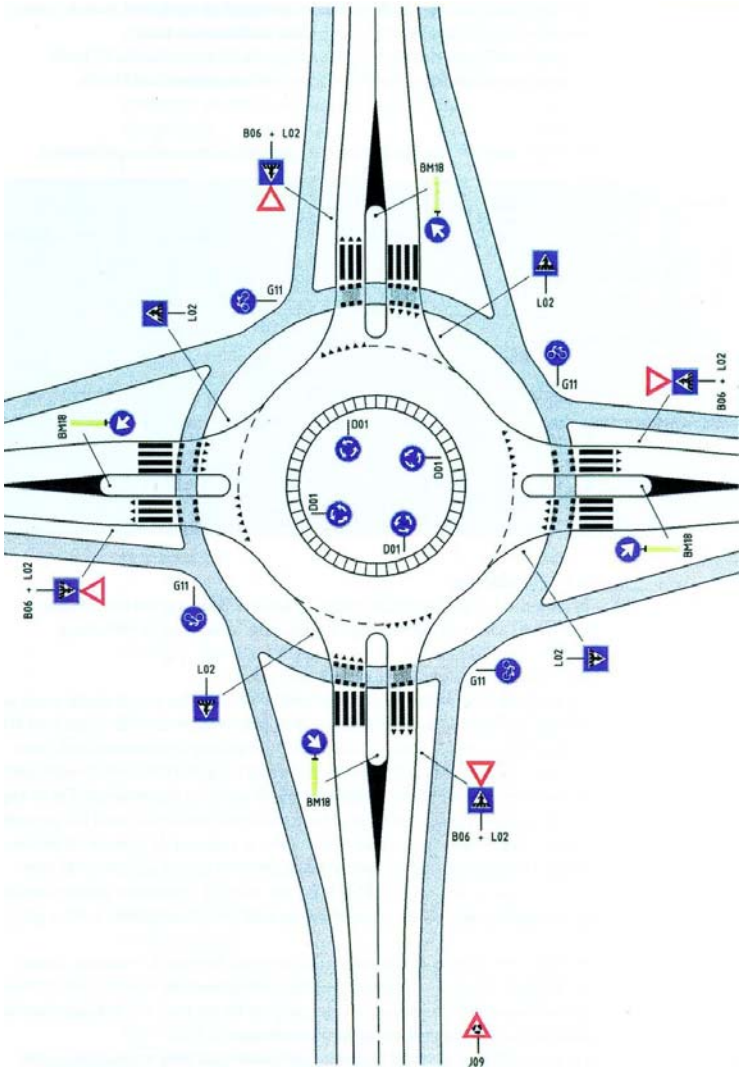


Exhibit 11 Geometric design for a roundabout that gives cyclists right-of-way (CROW, 1998)

Exhibit 12 shows the geometric design with the opposite right-of-way system. In the right-of-way system in which moped riders and cyclists do not have right-of-way, it is very important that these road users are required to make a veering movement before crossing:

- to act as a legal support for the fact that the moped riders and cyclists have to yield the right-of-way
- to reduce the speed of these road users

The importance of this veering movement for promoting the safety of moped riders and cyclists has been demonstrated previously. Research conducted by such agencies as the Province of South Holland into the effect of this outward curving of cycle tracks at T-intersections has demonstrated that the swaying movement promotes safety among moped riders and cyclists by slowing their speed and improving their attention. This design also saves space at the angles between the connecting roadways and the roundabout.

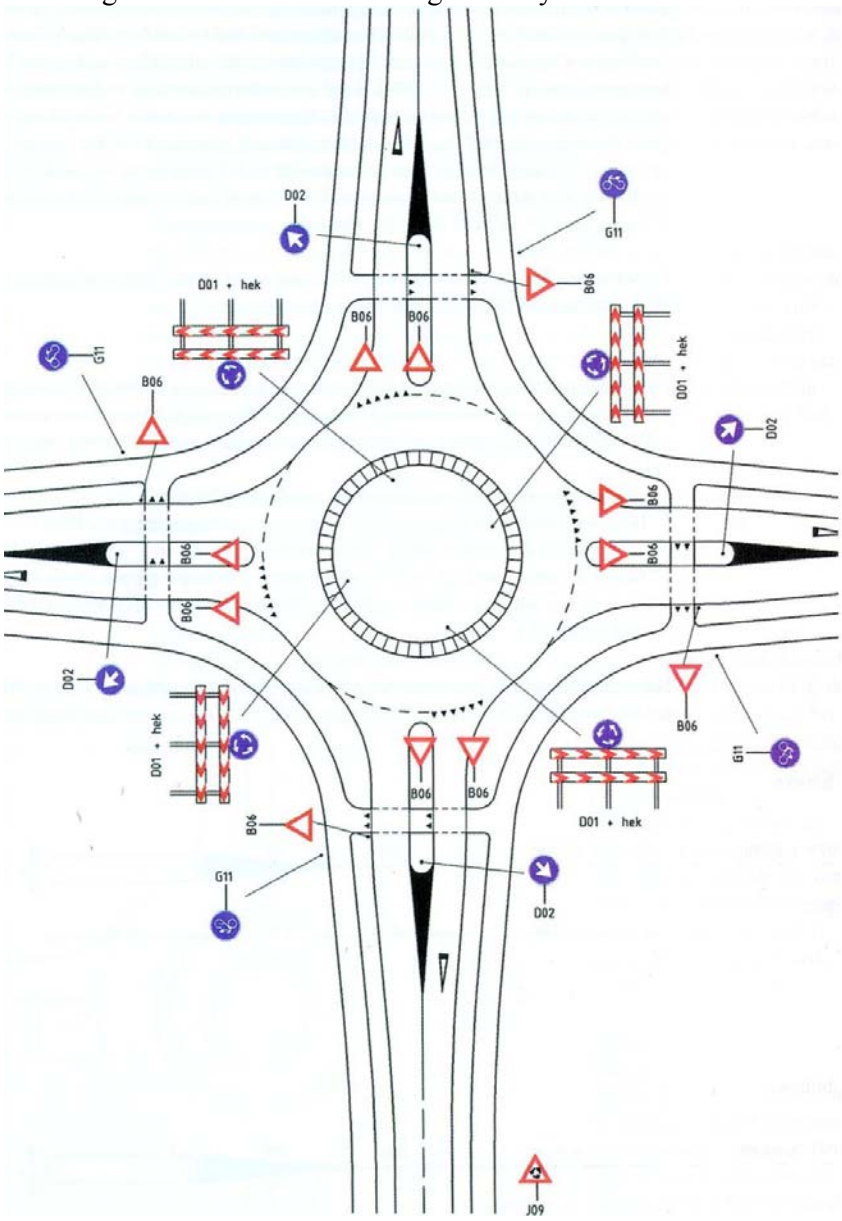


Exhibit 12 Geometric design for a roundabout that does not give cyclists right-of-way (CROW, 1998)

3.2 Recognizability of the various right-of-way regulations

TNO-Human Factors (TNO-TM, 2001) conducted a study into the design characteristics with which bicycle crossings are identified as giving the cyclist the right-of-way or not. A summary of the most important conclusions were:

1 contrary to what was previously thought, the environment in which the roundabout is located (urban or rural) had no significant effect on assessing the right-of-way regulation.
2 more than 90 % of the road users based their assessment of the right-of-way situation on the pavement markings (yield symbols representing a row of right-of-way signs), the red pavement marking the bicycle crossing, and the corresponding signposting (right-of-way signs).

This means that the visibility of the right-of-way marking for the road users who have to yield the right-of-way as well as for those who have it is of great importance.

3.3 The effect of bicycle traffic right-of-way regulation on capacity and delay

The solution giving cyclists the right-of-way actually has a harmful effect on the modern roundabout's ability to keep itself free of congestion. This incurs a risk that bicycle traffic can start clogging up the traffic on the roundabout. Nevertheless, the chance that this will happen is not that great, especially when cyclists cross the connecting roadway using a separate cycle track running 5 metres along the roundabout. The degree to which cyclists with the right-of-way will adversely affect capacity strongly depends on the degree to which cars on that roadway are already having to wait for the traffic on the roundabout. The more often cars have to wait for the motorized traffic on the roundabout, the less effect cyclists with right-of-way will have on reducing capacity on a separate cycle track. Obviously, this applies only to cars entering the roundabout, not the ones leaving it. (It should be noted that the effect cyclists have on reducing capacity on a connecting cycle lane will be much stronger; in this case, the impact of the cyclists will be added to the effect of the motorized traffic on the roundabout.) Assuming a direction distribution of 50% straight on, 25% turning left and 25% turning right at all connecting roadways, the reduction in the capacity of the separate cycle track having the right-of-way that will result from fewer than 150 cyclists per crossing per hour will be limited to 1%, while 300 cyclists per crossing per hour will reduce the capacity of the entire roundabout's traffic by 8% [De Leeuw, 1999].

3.4 The effect of bicycle traffic right-of-way regulation on safety

Various studies have been conducted in the Netherlands into the effect right-of-way regulation for cyclists has on safety. The most recent one was the study conducted by Wendy Weijermars [Weijermars, 2001]. The most important conclusions from that study involve roundabouts on which cyclists have the right-of-way. This study is examined here in more detail.

This study showed that two factors are very important in the solution where cyclists have the right-of-way:

a The distance between the cycle track and the circulatory roadway has to be wide enough (i.e. 5 metres); a dimension narrower than this can adversely affect safety.
b The greater the percentage of cyclists travelling in the opposite direction, the more this can adversely affect safety.

In addition, as based on observation of actual situations, it can be concluded that trucks in particular form a threat to moped riders and cyclists who make use of their right to priority. In a curve, truck drivers cannot easily see cyclists riding next to them. However, the design of Exhibit 11 assumes that moped riders within a built-up area will be making use of the roadway.

It has also been shown that many roundabouts in the Netherlands that give moped riders and cyclists the right-of-way have not been built according to the CROW recommendations. In particular, the distance criterion of having 5 metres between the cycle track and the circulating roadway is not being satisfied. The cause for this is usually the lack of space. As a result, research into roundabouts giving cyclists the right-of-way found that three times as many accidents took place on these compared to roundabouts where cyclists did not have the right-of-way: an average of 0.8 versus 0.3 injury accidents a year. For accidents occurring between fast and slow traffic, the difference could be multiplied by a factor of 6: an average of 0.6 versus 0.1 injury accidents a year. Based on statistics, the conclusion to be drawn was that this kind of roundabout is significantly less safe than roundabouts where the cyclists have to yield the right-of-way. Although this is contested by the Dutch Cyclists' Union, the SWOV Institute for Road Safety Research has qualified it as "very significant".

In situations of low-volume fast traffic, the study showed that the difference in injury accidents between both right-of-way regulations was not significant. Neither was there a significant difference between the right-of-way regulations in situations of low-volume slow traffic. The research also showed that the volume of the party having right-of-way has the most effect on the variation in the numbers of injury accidents. At roundabouts where cyclists had the right-of-way, this correlation was strongest (i.e. with the number of cyclists).

The roundabouts at which the distance between the cycle track and the circulatory roadway did meet the recommended 5 metres were still found to be unsafe but to a lesser degree. In this study, the difference involved a factor of 2. But the number of roundabouts that met the CROW recommendations in 1998 was so small that this difference was not significant enough to be considered reliable.

3.5 Approaching the issue of safety from an analysis of the traffic task

The findings from Weijermars' study can be well accounted for by an abridged task analysis that was conducted earlier by traffic psychologist Frank J.J.M. Steyvers from the Centre for Environment and Traffic Psychology. His conclusion, formulated as a proposition is: "Because the traffic task on a roundabout is very mentally demanding for car and truck drivers and involves certain tasks that are impossible to perform, fast traffic should have the right-of-way on roundabouts over slow traffic"[VERDI, 1999]. This analysis can be summarized as follows: "Upon leaving the roundabout, the primary tasks are maintaining one's course and taking the proper exit. Drivers will be devoting their limited amount of mental capacity to these tasks. Observing moped riders cannot be handled until just before and/or just after the turn has been made." In the working paper, he added another proposition to this: "It is better to strive for a right to maximum safety than for a right to have the right-of-way".

The risk for making mistakes is also relatively high when approaching the roundabout if the driver first has to yield the right-of-way to bicycle traffic on the cycle path and then to the

motorized traffic on the roundabout. Research has showed that repeating a cycle of "observe – decide – act" within one to two seconds considerably increases the chance of making mistakes [Rassmussen, 1989].

Nevertheless, and in agreement with the Dutch Cyclists' Union, the CROW study group that puts together the Dutch guidelines continues – when it comes to roundabouts inside built-up areas – to put the convenience of cyclists high on the priority list – possibly higher than their safety. [CROW, 2002]. This standpoint must also be seen against the background that the available research material did not allow the confident drawing of a conclusion in favour of roundabouts that had been built in conformance with the CROW recommendations. Additional research into this is needed for the purpose of being able to draw definite conclusions.

The government of the Province of South Holland supports the implementation of the guideline. It really should be possible within built-up areas to realize a geometric design for a roundabout that will be in accordance with the guideline. If the roundabout is located on a through road passing through a built-up area, the character of the road will be considered as well: the amount of truck traffic (infrequent semi-trailer use: less than ca. 5 percent of the total traffic), the location of the moped riders (on the roadway or on the cycle track?), the presence of two-way cycle tracks, and the number of lanes to be crossed.

3.6 Conclusions on the right-of-way

The Dutch guideline recommends the same right-of-way system for cyclists as the ones given for pedestrians in the exhibits in the FHWA guideline: in built-up areas (urban), they have the right-of-way; outside built-up areas (rural), they have to yield. Due to the higher speed of cyclists, cyclists with the right-of-way make the drivers' task more difficult: the drivers' anticipation time is extremely critical and can have adverse effects on safety. In any case, it is clear that the distance between the cycle track and the roundabout is very important: this must be at least 5 metres. There are still not enough research findings available to be able to make a definite statement about the safety of this solution. But convenience considerations for bicycle traffic have been the deciding factor in formulating the recommendation as it stands now. Additional research is needed to determine the consequences of this in regard to safety.

4 DESIGNING BICYCLE AND PEDESTRIAN CROSSINGS

4.1 Point of departure

In designing pedestrian and bicycle crossings at roundabouts, the traffic participant's opportunity to anticipate plays an important role. The rule of thumb that there should be at least one second between each observe-decide-act cycle (and preferably, two seconds) provides a good basis for designing. What also applies, however, is the stipulation that this time span should not become so great that other factors such as an increase in speed or a greater effect of surprise can start to have an adverse effect.

4.2 Single-lane crossing

In the Netherlands, guidelines indicate a minimum distance of 5 metres between the circulatory roadway and the bicycle crossing for roundabouts giving cyclists the right-of-way. It should be clear that this dimension is inadequate when it comes to the being able to anticipate. Not surprisingly, this dimension was arrived at as based on a compromise between a minimum limit for being able to anticipate and the space required for this.

When moped riders and cyclists are not given the right-of-way, the distance to the circulatory roadway is determined primarily by legal considerations. It should be clear that the cycle track is not simply part of the same road as the roundabout's main roadway. In the Netherlands, this is the case after the point where the car has completed its turning movement. This is the same as the point where the roundabout's exit radius meets the side of the exit lane. Usually, this is a distance of 6 metres. The Dutch guideline recommends the use of 10 metres as the distance between circulatory roadway and bicycle crossing.

The pedestrian crossing is always located further from the roundabout and next to the cycle track. If cyclists have the right-of-way, a zebra crossing that gives pedestrians the right-of-way over motorized traffic should be included as well. For the sake of clarity, pedestrians, too, have to yield to motorized traffic outside built-up areas. The marking is then altered to suit this purpose: pavement marking is not used for pedestrians.

4.3 Double-lane crossing

When crossing more than one lane, it would definitely be desirable for bicycle traffic to have access to crossing at a different level. This is why bicycle tunnels are included in the package of functional requirements in new situations. Nevertheless, there are many existing situations in which realizing this would involve unacceptable social costs. When this happens, the best (a bicycle tunnel, which cannot realised) can become the enemy of the better (a turbo-roundabout with bicycle crossings). For the sake of completeness, it should be mentioned that safety is also a major problem at bicycle crossings at intersections regulated by traffic lights.

For these reasons, CROW publication 126 also shows solutions in which the bicycle traffic crosses two approach lanes for motorized traffic and only one exit lane. It can now be wondered whether a solution in which bicycle traffic would cross two exit lanes would essentially be any different. The CROW publication suggests it would be although this is not substantiated by accident statistics. When the bicycle crossing is located at the proper distance from the roundabout (not too close because in rounding a curve, the motorist is very focused on the steering task; not to far away because the speed has to be kept low) crossing a double-lane approach lane could sometimes be more dangerous. Accident statistics for roundabouts where cyclists have to yield provide no conclusive evidence that the exit is more hazardous to cross than the access.

It is plausible to conclude, however, that crossing double lanes is automatically more dangerous than crossing a single lane. This is why it is important that the driver's observing and deciding time between those two crossings be more than two seconds, while the cyclist is getting into position for the second crossing in such a way that he/she has a good picture of the motorized traffic. This is why the Province of South Holland equips these crossings with a castling (or jog). Due to this construction, the crossing of two double approach and exit lanes is expected

not to be any more dangerous than crossing a double approach lane combined with a single exit lane without a making a castling movement.

It takes pedestrians longer to cross. For this reason, no castling movement is necessary to create sufficient time for anticipation.

Exhibit 13 Bicycle castling (jog) located immediately next to a pedestrian crossing

4.4 Conclusions geometric design pedestrian and bicycle crossings

To give the possibility for anticipating what the party with the right-of-way is going to do, is a very important aim by designing of pedestrian and bicycle crossings. When cyclists have the right-of-way the proper design should give enough time to drivers to anticipate this. The minimum distance of 5 metres between roundabout and crossing is then too small to detect fast cyclists but from the standpoint of taking up space, as well as the legal consideration that the bicycle crossing has to belong to the same road, can hardly be significantly enlarged. In reality, there is even a great tendency to use a smaller distance.

In the case of pedestrians and cyclists without right-of-way, anticipating is primarily a matter for the pedestrians and cyclists. Because crossing two double lanes requires a lot from these road users, an anticipation time of 2 seconds would be desirable. For cyclists, this can be achieved by introducing a shortcut in the form of a castling on a splitter island having a width of 7 metres. Due to the slower speed of pedestrians, a distance of 3 metres between the approach roadways and the exit roadways will be sufficient to provide an observation time of 2 seconds.

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