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Compact accident research

Safety at Roundabouts in Built-Up Areas

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Wilhelmstraße 43/43G, 10117 Berlin
PoBox 08 02 64, 10002 Berlin
unfallforschung@gdv.de
www.udv.de

Editors: Dipl.-Ing. Jörg Ortlepp, Dipl.-Ing. Heiko Voß
Layout: Franziska Gerson Pereira
Photo references: Insurers Accident Research

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Preliminary remarks

Small roundabouts are rightly considered to be extremely safe traffic control devices both in Germany and elsewhere. However, cyclists benefit least from the improved safety they bring.

The German findings are based on older studies whose usefulness is now compromised because the studies carried out in the 90s generally investigated roundabouts that are no longer state of the art.

More recent studies focus exclusively on bicycle traffic and pedestrians and are based on a relatively small amount of data.

In a current study carried out by Bochum-based Brilon, Bondzio, Weiser Ingenieurgesellschaft für Verkehrswesen mbH for the UDV (German Insurers Accident Research), a comprehensive analysis was carried out of the safety of roundabouts in built-up areas designed largely in accordance with the current guidelines.

The deployment and design recommendations in the current guidelines were subjected to a critical examination in the study. One of the main aspects focused on in the study was how cyclists and pedestrians are guided through the roundabout.

Content

Introduction

A roundabout is an intersection or junction that links three or more roads by means of a circular, unidirectional flow of traffic. Roundabouts have a central island around which the traffic flows.

Roundabouts have a number of advantages over normal intersections or junctions:

- Since there are no vehicles turning left across oncoming traffic, there are fewer points of conflict.
- The continuous flow of traffic along the road is interrupted, which reduces the speed of the traffic both before it enters the roundabout and in the roundabout itself.
- The low speeds and reduced number of points of conflict ensure a very high level of road safety compared to other forms of intersection.
- Road users, whether they are drivers, cyclists or pedestrians, can generally negotiate a roundabout without having to wait very long.

Roundabouts in Germany should be planned and implemented in accordance with the 2006 edition of the "Merkblatt für die Anlage von Kreisverkehren" (roundabout design guidelines) published by the FGSV (Forschungsgesellschaft für Straßen- und Verkehrswesen). The publication distinguishes between three types of roundabout:

Mini-roundabouts are used primarily in built-up areas and generally have a diameter of between 13 and 22 meters. They are suitable, in particular, for low and moderate traffic volumes (up to 18,000 motor vehicles a day) and can often be put in place without the need for extensive roadworks. It must be possible to drive over the central island of mini-roundabouts to ensure that larger vehicles can negotiate these roundabouts.

Small roundabouts, on the other hand, have a central island that is structured in such a way that it is not possible to drive over it. They have a diameter of 26 to 35 meters and can also be used for higher traffic volumes (up to around 25,000 motor vehicles a day). The circular roadway around the roundabout's central island is generally subdivided into an inner ring and the main driving lane. The width of the main driving lane is such that only larger vehicles have to use the inner ring. The inner ring may

Figure 1:
Mini-roundabout with traversable central island

Figure 2:
Small roundabout with raised inner ring

be simply marked out or raised above the rest of the roadway. If large volumes of traffic (up to 32,000 motor vehicles a day) go through the roundabout, the roundabout's roadway can be widened to allow two vehicles to negotiate it side by side. In this case, the diameter is at least 40 meters.

If there are multiple lanes in the roundabout's circular roadway, it is considered to be a **large roundabout**. These roundabouts are suitable for high volumes of traffic (over 30,000 motor vehicles a day) but should only be used in combination with traffic lights. **Turbo-roundabouts** are a particular type of large roundabout at which drivers have to choose a specific lane before entering the roundabout in order to take their desired exit road from the roundabout.

The current UDV study is exclusively concerned with the safety of small roundabouts in built-up areas consisting of a single lane designed in accordance with the FGSV guidelines.

Figure 3:
Large roundabout without traffic signals

Procedure

Examination of the literature
Research work and publications with direct relevance to the issues studied were selected. Sources from Switzerland, Austria and the Netherlands were examined, in addition to German research and publications, because these countries have similar recommendations on the design of roundabouts.

Macroanalysis of accidents
In the federal state of North Rhine-Westphalia, not only is there a systematic indication in the traffic accident report that the accident took place at a roundabout; in addition, the catalog of three-digit accident types is used. A detailed examination of the accident statistics was undertaken there over a six-year period.

Microanalysis
100 roundabouts in different federal states that essentially comply with the current design standards were selected for the microanalysis. A total of 1,015 accidents in categories 1 to 6 were analyzed over a period of three years.

Observation of behavior at roundabouts
The traffic at ten selected roundabouts was analyzed in detail. Typical patterns of behavior of road users were investigated by analyzing 5-hour video recordings.

Recommendations
Recommendations were formulated based on the findings.

Examination of the literature

The analysis of German studies as well as studies elsewhere in central and northern Europe allowed the following conclusions to be drawn:

- Roundabouts are a safe form of intersection in built-up areas as well. The studies involving a before-and-after comparison came unanimously to the conclusion that constructing an intersection into a roundabout had improved road safety. In studies with a control group, the improvement in safety was less marked than in studies without a control group.
- The fall in accidents involving serious injuries following the construction of a roundabout is a particularly positive development.
- Drivers and pedestrians benefit, in particular, from the improvement in safety.
- The various studies obtained different results with regard to the safety of cyclists. However, they unanimously indicated that cyclists benefit less from the improvement in safety than other road users. While one study in the Netherlands found that the risk of an accident fell for cyclists, other studies showed that the risk remained about the same. In the studies that showed an increase in the risk of an accident for cyclists, the results were not differentiated adequately by roundabout type or in terms of how cyclists were guided through the roundabout.

Macroanalysis of accident occurence

The safety or lack of safety of traffic control devices manifests itself, above all, in the accident statistics. Since the police accident statistics in North Rhine-Westphalia include the roundabout as a special attribute describing the accident location, purposeful analyses of the accidents occurring at roundabouts can be carried out there in a way that is not possible in most other federal states.

The accident data of accident categories 1 to 4 and 6 for the years from 2004 to 2009 was made available by North Rhine-Westphalia's state office for central police services. Of

397,647 accidents in categories 1 to 4 and 6 in built-up areas in the years from 2004 to 2009, almost 54 % occurred at intersections or junctions.

The very small percentage of accidents that take place at roundabouts shown in Figure 4 does not give any indication of the level of safety at roundabouts because there is no information provided about how common each type of intersection is or the total length of all stretches of road.

Figure 5 shows how all accidents involving injuries are distributed among accident categories 1 to 3 for each type of intersection.

It shows that the percentage of accidents involving serious injuries at roundabouts is lower than at signal-controlled or non-signal-controlled intersections.

Accident category 1	Fatal accident
Accident category 2	Accident with serious injuries
Accident category 3	Accident with minor injuries
Accident category 4	Serious accident with damage to property
Accident category 5	Other accident with damage to property
Accident category 6	Other accident with damage to property under the influence of alcohol

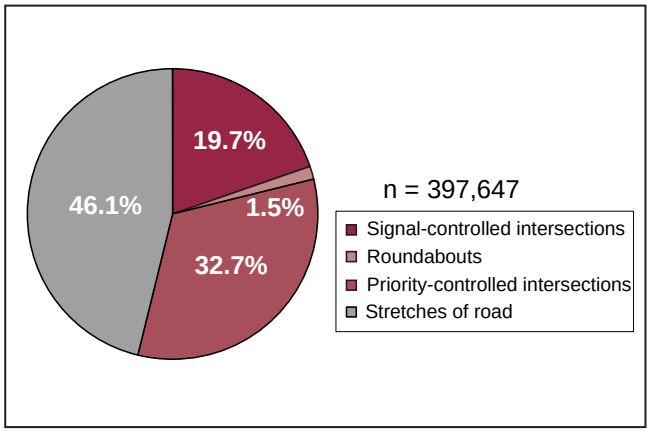

Figure 4:
Accidents within built-up areas in North Rhine-Westphalia from 2004 to 2009

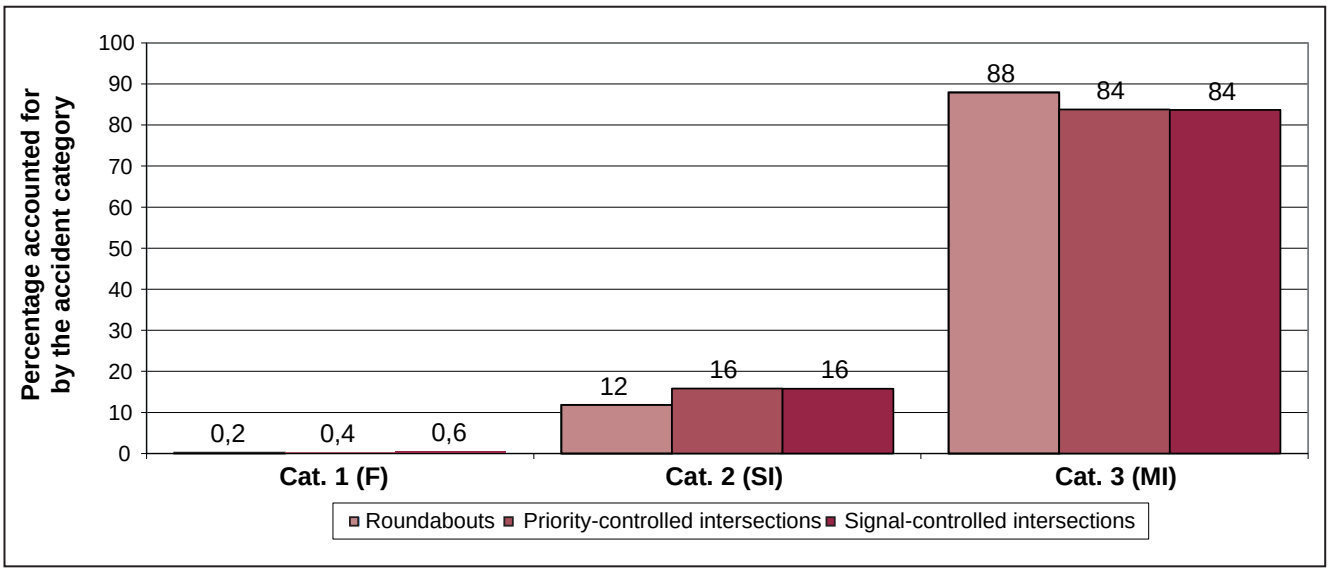

Figure 5:
Percentages of accidents involving injuries accounted for by accident categories 1 to 3 at the different types of intersections

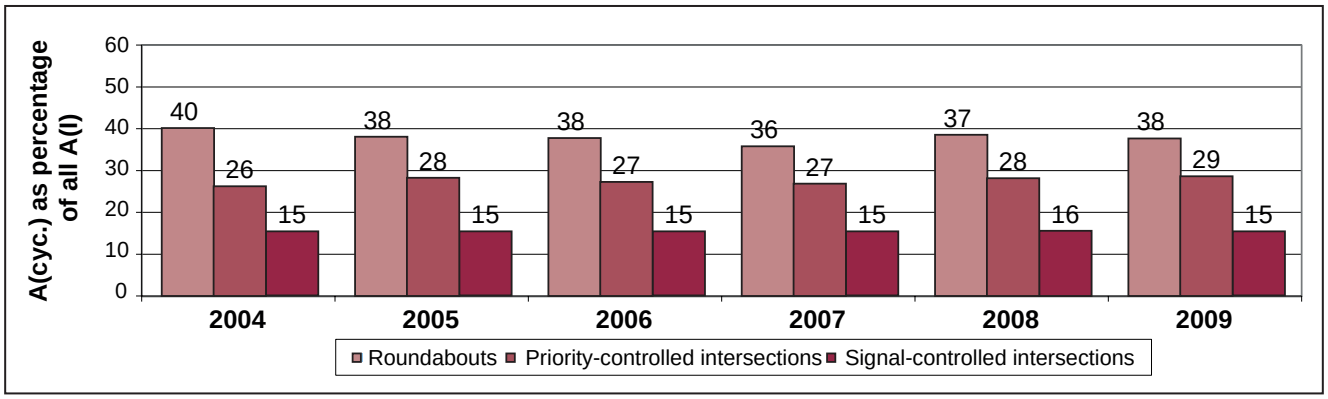

Figure 6:
Percentage of all accidents involving injuries accounted for by accidents involving cyclists

Figure 6 shows the percentage of all accidents involving injuries accounted for by accidents involving cyclists. It can be seen that cyclists at roundabouts are twice as likely to be involved in accidents involving injuries as cyclists at signal-controlled intersections. The percentage of cyclists involved in accidents involving injuries is also a third higher at roundabouts than it is at priority-controlled intersections.

In addition, it can be seen that the various percentages remain relatively constant from one year to another. However, it should be noted that there are fewer accidents involving injuries at small roundabouts in total than at other types of intersection.

Microanalysis of accident occurence

In order to determine why cyclists do not benefit from the high level of safety at small roundabouts to the extent that other road users do, 100 roundabouts were selected from over 500 for a detailed analysis.

The selection was made using the following criteria:

- Location in built-up areas
- Location in different federal states
- Different types of built-up area (urban, village)
- Different types of surrounding area (e.g. town center, residential area, commercial area)
- Year of opening to traffic before 2008
  Design very largely in accordance with the guidelines. The design guidelines require an external diameter of between 26 and 40 meters. 95 of the roundabouts examined were within this range.
- Different forms of guidance for cyclists and pedestrians
  44 of the 100 roundabouts selected for microanalysis had cyclists in mixed traffic on the circular roadway (Figure 7), 41 had cycle paths around the perimeter on which cyclists had priority when crossing the entry and exit roads (Figure 8), and 15 had cycle paths around the perimeter on which cyclists had to give way to drivers when crossing the entry and exit roads (Figure 9).
- Different traffic volumes for motor vehicles, cyclists and pedestrians
  The traffic volumes for motor vehicles ranged from 5,000 to just over 25,000 in a 24-hour period. There were between 100 and 7,000 cyclists in a 24-hour period. A third of the roundabouts had under 600 cyclists, a third between 600 and 1,200 and a third over 1,200 in a 24-hour period. Around half of the roundabouts had at least 100 pedestrians crossing in a two-hour period. At one round-

Figure 7:
Cyclist in mixed traffic

Figure 8:
Cycle path with priority for cyclists across roads

Figure 9:
Cycle path where cyclists must give way at roads

about, over 800 crossing pedestrians were counted in a two-hour period.

- Types of pedestrian crossing points
  At 58 of the roundabouts there were pedestrian crossings, and at 10 further roundabouts there were shared crossings with priority for cyclists and pedestrians. At the other 32 roundabouts, there were no markings for pedestrians at the entry and exit roads.

The accidents that occurred at these 100 roundabouts were analyzed in detail. The analysis was carried out on the basis of police accident reports for the years from 2008 to 2010.

Figure 10 shows the data collection procedure.

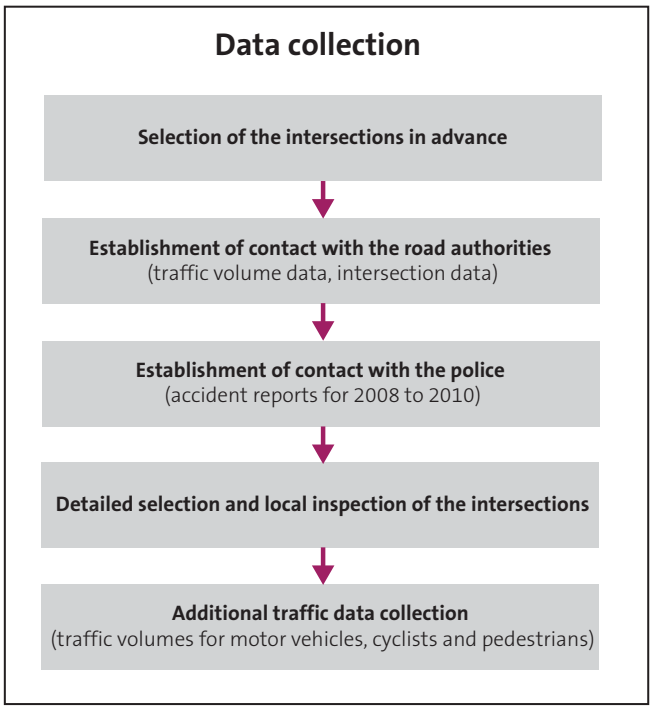

Figure 10:
Data collection procedure

Analysis of the accident structure

A total of 1,015 accidents were reported to the police at the 100 roundabouts analyzed in the period from 2008 to 2010.

Figure 11 shows the low percentage of accidents with serious consequences (categories 1 and 2).

In order to analyze the accidents involving cyclists in more detail, the accidents were differentiated on the basis of the three-digit accident types (Figure 12).

Much the most frequent accident types were type 3, which accounted for 47 % of all accidents, and type 6, which accounted for 37 % of all accidents. Within accident type 3, the

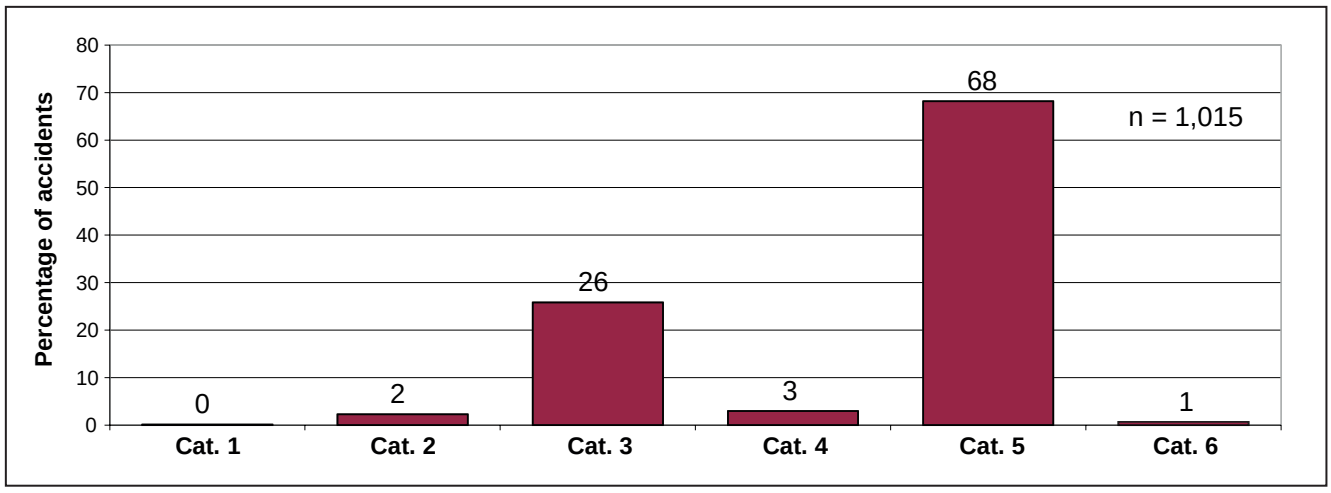

Figure 11:
Accidents by accident categories

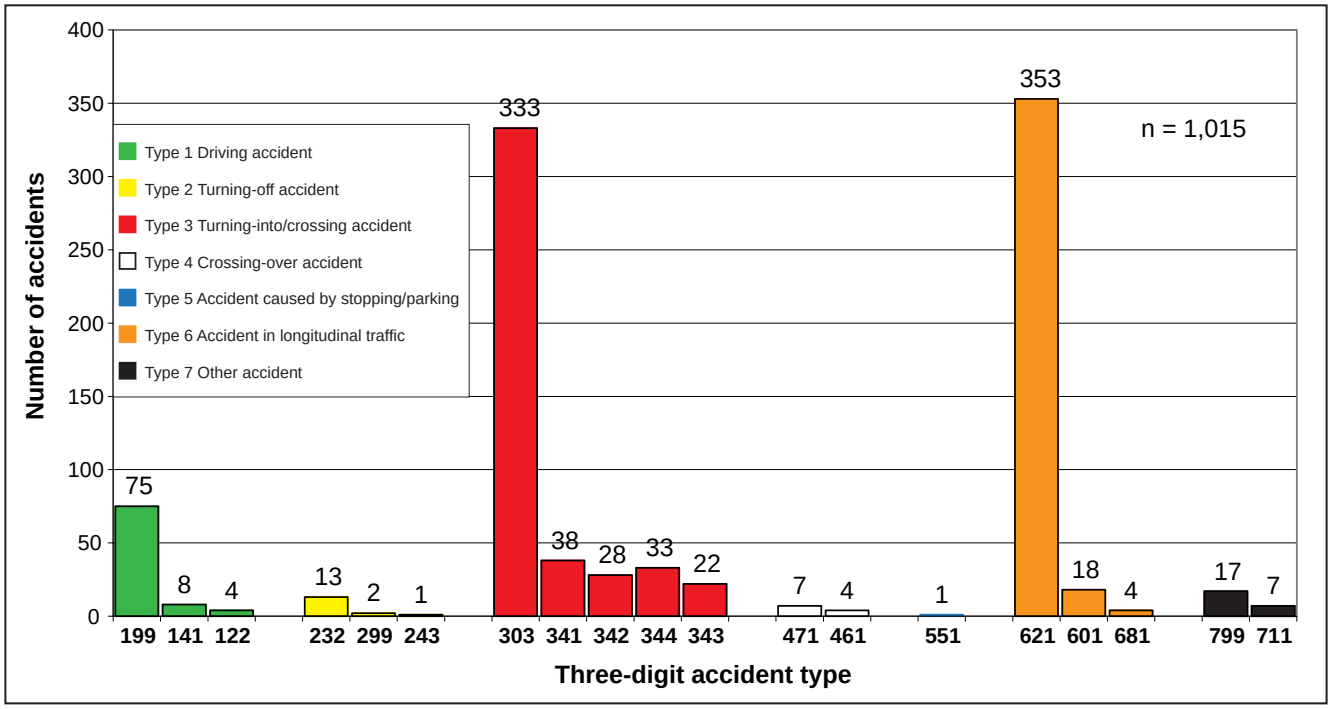

Figure 12:
Differentiation of the accident types

subtype 303 (failure to observe right of way rules on entering the roundabout) dominated, accounting for 33 % of all accidents. Accidents between motor vehicles and cyclists at crossing points accounted for a considerable 12 % of all accidents.

Accidents in longitudinal traffic occurred primarily in the form of subtype 621 (driving into the back of a vehicle required to wait on a road entering the roundabout at the roundabout's circular roadway or at the exits to the roundabout before the crossing points).

The analysis of the light conditions and state of the road revealed no conspicuous findings.

Traffic volume and accident occurence

With regard to the relationship between traffic volumes and accident indicators, the following results were obtained:

- There is no evidence of a linear relationship between the volumes of motor vehicle traffic and the accident rates or accident cost rates.
- There is, however, a linear relationship between the accident density and the volumes of motor vehicle traffic (with coefficient of determination of 0.33) and a weaker relationship between the accident cost density and the volumes of motor vehicle traffic (with a coefficient of determination of 0.21).
- There is no linear relationship between the volumes of bicycle traffic and the accident rates or accident cost rates.
- On the other hand, there is a linear relationship between the accident density of bicycle traffic and the volumes of bicycle traffic (with a coefficient of determination of 0.37). However, this relationship is significantly influenced by the accidents at a single roundabout. If this roundabout is not included, there is only a very weak linear relationship (with a coefficient of determination of 0.12).
- There is a linear relationship between the product of the motor vehicle and bicycle

traffic volumes and the accident density of bicycle traffic (with a coefficient of determination of 0.50). Here, again, the relationship is significantly influenced by a single roundabout. If this roundabout is not included, there is only a very weak linear relationship (with a coefficient of determination of 0.19).

- On the basis of all accidents, there is a linear relationship between the total traffic volumes for motor vehicles and bicycles and the accident density (with a coefficient of determination of 0.35).

No really strong relationships could be found in this study between traffic volumes and accident occurence, in particular accidents involving cyclists.

Forms of guidance of bicycle traffic and accident occurence

Forms of guidance with cycle paths around the perimeter of roundabouts with priority for cyclists at the entry and exit roads (cycle paths with priority parallel to a pedestrian crossing or shared paths for cyclists and pedestrians) proved to be the least safe. The accident cost rates were significantly higher for these (Figure 13) than for cycle paths around the perimeter where there was a give-way sign for cyclists (sign 205) at the roundabout's entry and exit roads and for roundabouts where cyclists were involved in mixed traffic on the main circular roadway.

Roundabouts with cycle paths around the perimeter where cyclists have priority over drivers entering and leaving the roundabout have the highest level of accident risk for cyclists compared with roundabouts with other arrangements for cyclists.

Intersection geometry and accident occurence

When the relationships between the geometry of roundabouts and accident occurence were investigated, the only conclusions that could be drawn were for the number of roads intersecting and the width of deflection on entering the roundabout:

- Roundabouts with five intersecting roads are significantly less safe than those with three intersecting roads. Roundabouts with four

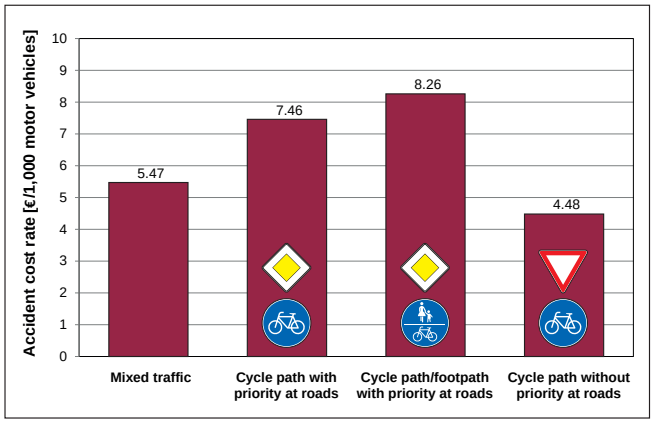

Figure 13:
Accident cost rates for roundabouts with different arrangements for cyclists

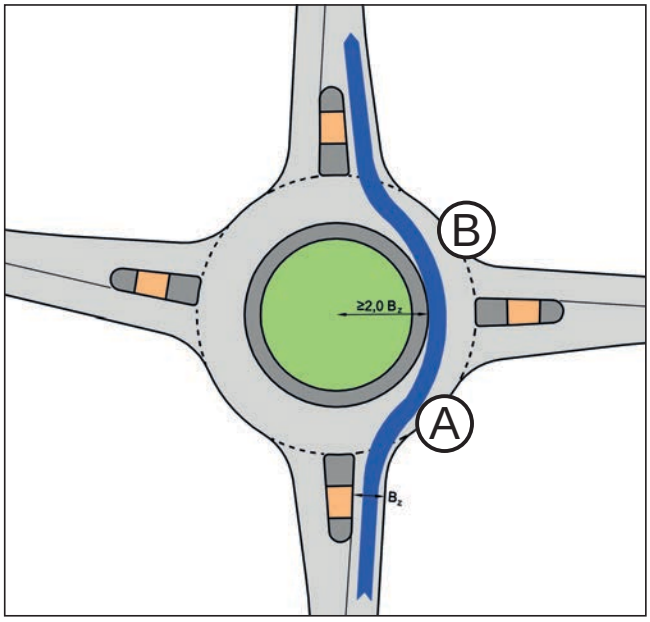

Figure 14:
Width of deflection

intersecting roads tend to be somewhat less safe than those with three intersecting roads.
- A weak relationship was found between the width of deflection and accident density. However, a significant relationship was found between the width of deflection and turning-into/crossing accidents at the intersecting road after the road of entry (Figure 14, B). The width of deflection at the vast majority of the roundabouts were as stipulated by the FGSV design guidelines for roundabouts.

In addition, no relationships could be found between accident occurence and geometric characteristics such as the external diameter, entry widths, exit widths or radius. This can be taken as an indication that the dimensions specified in the FGSV design guidelines are effective.

Observation of behavior at roundabouts

Video analysis was used to observe behavior at ten roundabouts for a period of five hours in each case.

The analyses focused on the behavior of cyclists and the interaction between cyclists and other road users. The following variables were used to describe the particular characteristics of the traffic flow:
- Use of the infrastructure and acceptance of the arrangements for cyclists
- The space occupied by cyclists on the roundabout's circular roadway
- Rule infringements
- Noticeable patterns of behavior
- Interactions.

The results can be summarized as follows: At **roundabouts with mixed traffic** there is a clear relationship between the traffic volume of motor vehicles and the acceptance of the arrangements for cyclists. The higher the traffic volume for motor vehicles, the lower is the percentage of cyclists who negotiate the roundabout in mixed traffic. Particularly at very busy roundabouts, more cyclists can be expected to use the sidewalks. However, the percentage of cyclists using the sidewalks to avoid the roadway is very low. Most cyclists who negotiate the roundabout on the sidewalks also use the sidewalks on the busy approach roads.

If the roundabout has a raised inner ring, this reduces the number of overtaking maneuvers in the roundabout and thus the likelihood of drivers cutting across cyclists dangerously at the exits to the roundabout.

At **roundabouts with cycle paths around the perimeter on which cyclists have priority when crossing the roads**, cyclists' acceptance of this arrangement is extremely high at 99 %. At least at times when traffic volumes are high, cyclists only use the roundabout's circular roadway in exceptional cases.

However, depending on the design of the roundabout, considerable numbers of cyclists are sometimes seen negotiating the roundabout in the wrong direction. The percentage of cyclists who negotiate the roundabout in the wrong direction varies very greatly, also from one locality to another, and depends, for example, on how far apart the cyclist's entry and exit roads are.

Cyclists generally appear confident and assertive where they have priority crossing the roads and seldom stop. However, considerable differences are evident from one roundabout to another. When cyclists travel in the wrong direction along cycle paths that give them priority when crossing the roads, they tend to adopt a more defensive approach.

Drivers generally respect the priority of cyclists and give way.

At **roundabouts with cycle paths around the perimeter** on which cyclists do not have priority when crossing the roads, cyclists' acceptance of this arrangement is very high as well. The average acceptance of this arrangement is only slightly lower than for roundabouts with cycle paths around the perimeter on which cyclists have priority when crossing the roads.

Cyclists are generally more cautious and less assertive at these crossing points than at crossing points where they have priority. They watch the traffic more closely on approaching the crossing point. If interaction appears to be about to occur, there is generally communication between the cyclist and driver.

The percentage of cyclists who stop or get off their bicycles is higher on average than at crossing points where they have priority.

Despite having priority, many drivers give way to cyclists at the crossing points.

Recommendations

The FGSV design guidelines for roundabouts are very largely validated by the results of this study. Single-lane roundabouts in built-up areas that are designed in accordance with the guidelines have a high level of safety, and this is evident in the low numbers of accidents that occur.

The high level of safety is achieved primarily due to the fact that the central island reduces drivers' speed by presenting them with a significant deflection as they enter the roundabout. This width of deflection cannot always be maintained beyond doubt in practice. When inner rings are merely marked out or are not significantly higher than the roundabout's roadway despite being a separate structure, the deflection should be specified more precisely. Inner rings like this should not be included in the calculation of the width of deflection. To reduce the danger of cyclists being overtaken by motor vehicles in mixed traffic, the inner ring should always be significantly raised above the level of the roadway.

The generally high level of safety at roundabouts designed in accordance with the guidelines is not achieved to the same extent when cyclists are guided onto cycle paths around the perimeter on which they have priority at the crossing points. It is therefore recommended that cyclists are made to give way by erecting a give-way sign, which is sign 205 of the German road traffic regulations (StVO). However, to make sure everyone understands the situation correctly, this also entails doing without pedestrian crossings, and in built-up areas that is only justifiable in locations where there are low numbers of pedestrians.

The safest arrangement for cyclists at roundabouts was revealed to be mixed traffic on the roundabout's circular roadway. Particularly when the roundabout's inner ring is clearly raised above the level of the roadway, a high level of safety can be achieved for cyclists even when traffic volumes are high. However, when there are high volumes of motor vehicles, cyclists increasingly use the sidewalks on the approach roads and stay on them to negotiate the roundabout. This should be taken into account in the FGSV design guidelines in future as well as in the current planning of roadside areas.

German Insurance Association

Wilhelmstraße 43/43G, 10117 Berlin
PO Box 08 02 64, 10002 Berlin

Phone: + 49 30/20 20 - 50 00, Fax: + 49 30/20 20 - 60 00
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