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Design types of cycle facilities at roundabouts and their effects on traffic safety: some empirical evidence

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ABSTRACT

Roundabouts in general have a favourable effect on traffic safety, at least for crashes causing injuries. Especially the number of severe crashes (fatalities and crashes involving serious injuries) appears to decrease after converting intersections into roundabouts.

Less is known about the safety effects of roundabouts for particular types of road users, such as bicyclists. A before-and-after study with the use of a comparison group on a sample of 90 roundabouts in Flanders-Belgium was conducted in order to assess the effects on crashes with bicyclists. This study revealed a significant increase in the number of severe injury crashes with bicyclists after the construction of a roundabout. Roundabouts with cycle lanes perform worse, regarding injury crashes with bicyclists, compared to three other design types (mixed traffic, separate cycle paths and grade-separated cycle paths). Roundabouts that are replacing signal-controlled intersections seem to have had a worse evolution compared to roundabouts on other types of intersections.

1. INTRODUCTION

Roundabouts in general have a favourable effect on traffic safety, at least for crashes causing injuries. During the last decades several studies were carried out into the effects of roundabouts on traffic safety. A meta-analysis on 28 studies in 8 different countries revealed a best estimate of a reduction of injury crashes of 30-50% (Elvik, 2003). Other studies, not included in the former one, delivered similar results (e.g. Persaud et al., 2001; De Brabander et al., 2005). All those studies reported a considerably stronger decrease in the number of severest crashes (fatalities and crashes involving serious injuries) compared to

the decrease of the total number of injury crashes. The effects on property-damage only crashes are however highly uncertain (Elvik, 2003).

Less is known about the safety effects of roundabouts for particular types of road users, such as bicyclists (Daniels and Wets, 2005). Roundabouts seem to induce a higher number of bicyclist-involved crashes than might be expected from the presence of bicycles in overall traffic. In Great-Britain the involvement of bicyclists in crashes on roundabouts was found to be 10 to 15 times higher than the involvement of car occupants, taking into account the exposure rates (Brown, 1995). In Flanders-Belgium bicyclists appear to be involved in almost one third of reported injury crashes at roundabouts. Own analysis of the available crash data records reveals a number of 1118 crashes with bicyclists on a total of 3558 reported injury crashes at roundabouts during the period 1991-2001. In general, only 14.6% of all trips (5.7% of distances) are made by bicycle (Zwerts and Nuyts, 2004). The apparent overrepresentation of bicyclists in crashes at roundabouts was the main cause to conduct an evaluation study on the effects of roundabouts, more specifically on crashes involving bicyclists.

2. TYPES OF CYCLE FACILITIES

Throughout different countries different designs have been developed for cycle facilities at roundabouts. Although huge differences between design practices in different countries continue to exist, some basic design types of cycle facilities at roundabouts can be distinguished. They are ordered into four categories:

1. Mixed traffic;
2. Cycle lanes;
3. Separate cycle paths;
4. Grade-separated cycle paths.

The most basic solution is to treat bicyclists the same way as motorised road users, which means that bicycle traffic is mixed with motorised traffic and bicyclists use the same entry lane, carriageway and exit lane as other road users. It is further called the “mixed traffic” solution (see figure 1). In many countries this is the standard design since no specific facilities for bicyclists are provided. In some countries it is common to apply the mixed traffic solution, even when bicycle lanes or separate cycle paths are present on approaching roads. In that case, the cycle facilities are bent to the road or truncated about 20-30 meter before the roundabout (CROW, 2007).

Figure 1 – Roundabout with mixed traffic

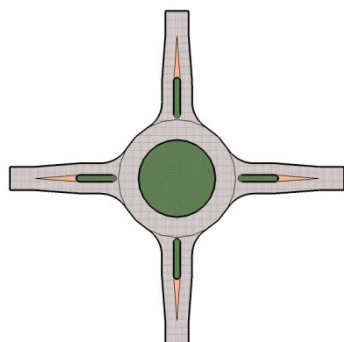


Figure 2 – Roundabout with cycle lanes

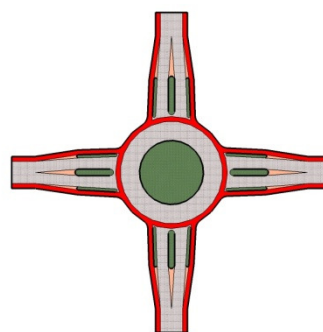


Figure 3a – Roundabout with separate cycle paths – priority to bicyclists

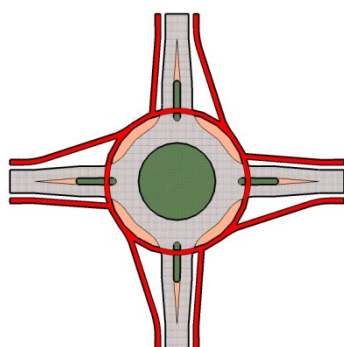


Figure 3b – Roundabout with separate cycle paths – no priority to bicyclists

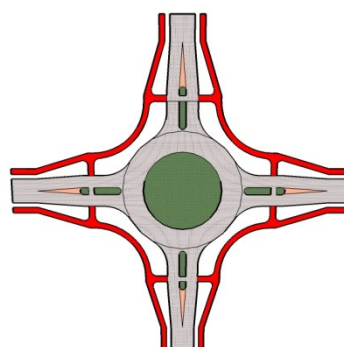
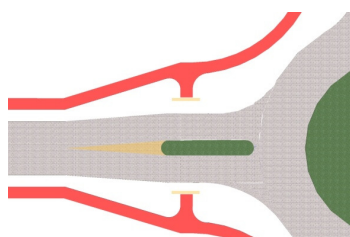


Figure 4 - - Roundabout with grade-separated cycle paths



A second possible solution are cycle lanes next to the carriageway, but still within the roundabout (figure 2). Those lanes are constructed on the outside of the roundabout, around the carriageway. They are visually recognizable for all road users. They may be separated from the roadway by a road marking and/or a small physical element or a slight elevation. They may also be constructed with a different pavement or differently coloured (red, green, blue...). However the cycle lanes are essentially part of the roundabout because they are very close to it and because the manoeuvres bicyclists have to make are basically the same as the manoeuvres for motorised road users.

When the distance between the cycle facility and the carriageway becomes somewhat larger (the operational criterion used in this study is: more than 1 meter), the cycle facility cannot be considered anymore as belonging to the roundabout. This is called the separate cycle path-solution. The 1 meter-criterion corresponds with the Flemish guidelines for cycle facilities (MVG, 2006) alongside roads. Since the distance between the separate cycle path and the roadway at roundabouts may amount to some meters (e. g. the Dutch design guidelines recommend 5 meters) (CROW, 2007), specific priority rules have to be established when bicyclists cross, while circulating around the roundabout, the entry or exit lanes.

While it is nowadays universally accepted to give traffic circulating on the roundabout priority to traffic approaching the roundabout, such is not always the case for bicyclists on separate cycle paths. At some roundabouts, priority is given to the bicyclists when crossing the entry/exit lanes, in other cases bicyclists have to give way. The former is called the “separate cycle paths - priority to bicyclists solution” (figure 3a), the latter the “separate cycle paths - no priority to bicyclists solution” (figure 3b) (CROW, 1998). When bicyclists have priority, this is supported by a rather circulatory shape of the cycle path around the roundabout allowing smooth riding (figure 3a). When bicyclists have no priority, the bicycle speed is reduced by a more orthogonal shape of the crossing with the exit/entry lane (figure 3b).

Finally, in a limited number of cases grade-separated roundabouts are constructed allowing bicycle traffic to operate independently from motorised traffic (figure 4).

3. DATA COLLECTION

A sample of 90 roundabouts in the Flanders region of Belgium was studied. The roundabout data were obtained from the Roads and Traffic Agency (part of the Ministry of Mobility and Public Works). The sample was selected according to the following successive selection criteria applied on the initial dataset:

- Roundabouts constructed between 1994 and 2000.
- 3 or 4 roundabouts selected randomly in each of the 28 administrative road districts in the Flanders region.

All the investigated roundabouts are located on regional roads (so-called numbered roads) owned by either the Roads and Traffic Agency or the provinces. This type of roads is characterized by significant traffic, where other, smaller and less busy roads are usually owned by municipalities. The Annual Average Daily Traffic on the type of roads in question is 11 611 vehicles per day (AWV, 2004). At the moment of the study no information was available about the AADT on the selected roundabouts. The investigated sample can be considered as representative for roundabouts on regional roads in Flanders.

Both single-lane as well as double-lane roundabouts occur in the sample, although the former type is far more common (83 of the 90 roundabouts).

Information was collected about the type of cycle facility that is present at the roundabouts (table 1). According to the type of the cycle facilities, each roundabout was assigned to one of the four above-mentioned categories.

Table 1 - Number of roundabouts in the study sample - location and type of cycle facility

	Inside built-up area	Outside built-up area	TOTAL
1 - Mixed traffic	8	1	9
2 - Cycle lanes	24	16	40
3 - Separate cycle paths	8	30	38
4 - Grade-separated	0	3	3
TOTAL	40	50	90

21 of the 90 roundabouts were replacing traffic signals. The other roundabouts were built on other types of intersections (intersections with stop signs, give way-signs or general priority to the right).

For the purpose of this study only roundabouts that were constructed between 1994 and 2000 were taken into account. Crash data were available from 1991 until the end of 2001. Consequently a time period of crash data of at least 3 years before and 1 year after the construction of each roundabout was available for the analysis. For each roundabout the full set of available crash data in the period 1991-2001 was included in the analysis.

Exact location data for each roundabout were available so that crash data could be matched with the roundabout data. 40 roundabouts from the sample are located inside built-up area (areas inside built-up area boundary signs, general speed limit of 50 km/h), 50 outside built-up areas (generally with a speed limit of 90 or 70 km/h).

Furthermore the colour of the cyclist facility (when present) was noticed. In Flanders it is common to colour cyclist facilities red, although it is not compulsory. Other colours don't occur. In the case of the cycle lanes, all but one are coloured. In the case of the separate cycle paths there are some more instances (6) of uncoloured pavements, but they are still limited to a small minority.

Two comparison groups were composed, consisting of 76 intersections inside built-up areas and 96 intersections outside built-up area respectively serving as a comparison group for roundabouts inside and outside built-up areas. For the comparison groups, intersections on regional roads were selected in the wide environment of the roundabout locations. Preference for comparison group locations was given to intersections on the same main road as the nearby roundabout location with the same type of crossing road. The road categories were found on a street map. In order to avoid possible interaction effects of the comparison group locations with the observed roundabout locations, comparison group locations had to be at least 500 meter away from the observed roundabout locations. Apart from the confirmation they aren't roundabouts, no information is available about the type of traffic regulation on the intersections in

the comparison group. On the considered types of roads either signal-controlled, or priority-ruled intersections (one direction has priority) may occur.

Detailed crash data were available from the National Statistical Institution for the period 1991-2001. This database consists of all registered traffic crashes causing injuries. Only crashes where at least one bicyclist was involved were included. Crashes were divided into 3 classes based on the severest injury that was reported: crashes involving at least one fatally injured person (killed immediately or within 30 days after the crash), crashes involving at least one seriously injured (person hospitalized for at least 24 hours) and crashes involving at least one slightly injured. No distinction was made about which road user was injured, the bicyclist or any other road user such as a car occupant, a motorcyclist, another bicyclist or whoever.

Locations of crashes on numbered roads are identified by the police by references to the nearest hectometre pole on the road. All the crashes that were exactly located on the hectometre pole of the location were included in this study. Subsequently crashes that were located on the following or the former hectometre pole were added, except when the observed crash could clearly be attributed to another intersection. This approach was chosen in order to include possible safety effects of roundabouts in the neighbourhood of the roundabout as they might occur (Hydén and Várhelyi, 2000). Consequently the results should be considered as “effects on crashes on or near to roundabouts”. At least one road on each location, both for the treatment group as for the comparison group, was a numbered road.

The same selection criteria were applied for crashes on locations in the comparison group as for crashes on the roundabout locations.

The total number of crashes on the roundabout locations was 411, of which 314 with only slight injuries, 90 with at least one serious injury and 7 with a fatal injury. The total number of crashes in the comparison group is 649, of which 486 with only slight injuries, 142 with serious injuries and 21 with fatal injuries.

4. METHODOLOGY

A before and after study was made of injury crashes with bicyclists at roundabouts. The first stage was to calculate the effectiveness for each location in the treatment group (= each of the 90 roundabouts) separately. The effect is expressed as an odds-ratio of the evolution of the number of crashes in the treatment group after the measure has been taken compared to the evolution in the comparison group over the same time period. An effectiveness-index EFF_1 above 1 indicates an increase in the number of crashes compared to the average evolution on similar locations where no roundabout was constructed, while an index below 1 shows a decrease in the number of crashes.

The use of the comparison group allowed for a correction of general trend effects that could be present in the evolution of crashes on the studied locations. The Empirical Bayes –methodology was used to correct for a possible regression-to-the-mean-effect. The regression-to-the-mean effect is likely to occur at locations where a decision has been taken to construct a roundabout as the Roads and Traffic Agency

considers an increased number of crashes among others as an important criterion for constructing a roundabout at a certain location. The used methodology is more extensively described in Daniels et al. (2008) and Daniels et al. (2009).

After executing all the calculations for the individual roundabout locations, a meta-analysis was carried out in order to retrieve generalized impacts on groups of locations. A meta-analysis is a useful procedure to combine results from different studies but combining the treatment effects of a set of entities within one study is conceptually highly comparable (Hauer, 1997).

Since additional data about geometric features of the roundabout were available some regression models could additionally be fitted in order to explain the variance of the estimated values of the effectiveness-indices according to changes in factors such as number of lanes, pavement colour, location inside/outside built-up area etc.

5. RESULTS

Tables 2 and 3 show the results of the analyses for all injury crashes and only crashes with fatally or seriously injured respectively. The best estimate for the overall effect of roundabouts on injury crashes involving bicyclists on or nearby the roundabout is an increase of 27%. The best estimate for the effect on crashes involving fatal and serious injuries is an increase of 42% which was almost significant at the 5%-level.

The number of injury crashes at roundabouts with cycle lanes turns out to increase significantly (+93%, C.I. [+38%;+169%]). However, for the other 3 design types (mixed traffic, separate cycle paths, grade-separated cycle paths) the best estimate is a decrease in the number of crashes (-17%), although not significant (result of a separate meta-analysis on the values for those categories, not reflected in the table). None of the partial results for one of the subgroups in table 3 is significant at the 5% level. However, all aggregated results show an increase in the number of fatal and serious crashes.

Table 2 - Results – all injury crashes.

	Nr of locations	Effectiveness-index
Mixed traffic	9	0.91 [0.45;1.84] (ns)
Cycle lanes	40	1.93 [1.38;2.69] **
Separate cycle paths	38	0.83 [0.56;1.23] (ns)
Grade-separated	3	0.56 [0.11;2.82] (ns)
All roundabouts	90	1.27 [1.00-1.61] *

ns = not significant * = $p \leq 0.05$ ** = $p \leq 0.01$

Table 3 - Results – crashes with fatal and serious injuries.

	Nr. of locations	Effectiveness-index
Mixed traffic	9	1.79 [0.56;5.74] (ns)
Cycle lanes	40	1.37 [0.79;2.35] (ns)
Separate cycle paths	38	1.42 [0.80-2.51] (ns)
Grade-separated	3	1.31 [0.23;7.54] (ns)
All roundabouts	90	1.42 [0.99;2.05] (ns)

ns = not significant * = $p \leq 0.05$ ** = $p \leq 0.01$

Subsequently a meta-regression procedure was applied. Maximum likelihood linear regression models (SAS-procedure GENMOD) were fitted in order to estimate the relationship between the estimated value for the effectiveness per location and some known characteristics of the roundabout locations. It was found that roundabouts with cycle lanes, compared with the other designs, have had a significantly worse performance regarding crashes with bicyclists. Furthermore the model showed that signal-controlled intersections that were converted into roundabouts have had a worse evolution than non-signal controlled intersections. Moreover, with somewhat looser model restrictions it was also found that two-lane roundabouts and roundabouts inside built-up areas had a positive, thus unwanted, effect on the estimated value for the effectiveness-index.

6. DISCUSSION

In our data, a clear difference in the performance level is visible for roundabouts with cycle lanes compared to other types when all injury crashes with bicyclists are considered. The presence of cycle lanes correlates with a higher value of the effectiveness-index which indicates an increase in the number of bicycle crashes. This effect was suggested earlier, e.g. by Brilon (1997).

Although a clear statistical relationship was found, the present results should be interpreted with some caution. Confounding factors might exist where was not controlled for. Moreover the specific effect for cycle lanes was not found for the subgroup of the severest crashes. Nevertheless we see two main reasons to be less confident in the result for the crashes with killed and seriously injured: first there is the very low fit of the model for the severe crashes, suggesting that much of the variance is purely random and/or could be explained by other, unknown, variables. A second reason is related to the reliability of the underlying data, i.e. the estimated values for the effectiveness-indices. The results for the individual locations for the crashes with killed or seriously injured have systematically low significance values. This forces us to rely substantially more on the results of the model for all the injury crashes, meaning that mainly roundabouts with cycle lanes perform worse. For the two remaining types of cycle facilities (mixed traffic and grade-separated), the models didn't reveal a distinct effect, which might be due to the scarcity of the data (9 and 3 observations respectively).

A Dutch before and after-study found no major differences in the evolution of crashes with bicyclists between three different roundabout design types (mixed traffic, cycle lanes, separate cycle paths) (Schoon and van Minnen, 1993). Regarding the numbers of victims however, it was concluded that at roundabouts with a considerable traffic volume, a separate cycle path design was safer than both other types. Therefore Schoon and van Minnen recommended the use of separate cycle path designs. In a Swedish study it was concluded that the bicyclist crash rate at roundabouts with cycle crossings (i.e. roundabouts with a cycle path design) was lower compared to roundabouts with bicyclists riding on the carriageway (Brüde and Larsson, 2000).

Earlier findings (Brüde and Larsson, 2000) suggested a weaker result for two-lane roundabouts compared to single-lanes. Our study reveals a similar tendency, but the results must be qualified as only indicative since they are insufficiently significant.

Roundabouts replacing signal-controlled intersections score weaker than roundabouts that replaced other types of intersections. A meta-analysis by Elvik (2003) revealed that the general favourable effect of roundabouts - although for all road users, not only for bicyclists - was greater on intersections previously controlled by yield signs than on signal-controlled intersections. In the present case, the same order of effect sizes seems to exist: also for crashes with bicyclists roundabouts replacing traffic signals perform worse compared to roundabouts on other types of intersections.

7. CONCLUSIONS

The main conclusions of this study can be summarized in four points:

1. The results for the study sample suggest that the construction of a roundabout generally raises the number of severe injury crashes with bicyclists, regardless of the design type of cycle facilities.
2. Regarding the effects on all injury crashes, roundabouts with cycle lanes perform worse compared to the three other design types (mixed traffic, separate cycle paths and grade-separated cycle paths).
3. Roundabouts that are replacing signal-controlled intersections seem to have had a worse evolution compared with roundabouts on other types of intersections.
4. Further research is needed in order to assess the validity of the results in different settings, such as other countries and other traffic conditions (e.g. depending on the prevalence of cyclists in traffic). Further research is also needed in order to extend knowledge about contributing factors and to reveal causal mechanisms for crashes with bicyclists at roundabouts.

No decisive answer can be given about which recommendations should be given to road authorities, based on the present knowledge of safety effects of roundabouts. The value of roundabouts as an effective measure to reduce injury crashes for the full range of road users has been well proven. The contrast with the effects on the subgroup of crashes with bicyclists is remarkable and may cause a dilemma in policy making. Based on the results for the severest crashes, it would not be recommendable

to construct a roundabout anyway when safety for bicyclists is a major concern. However, based on the results for all injury crashes, a clear distinction should be made between roundabouts with cycle lanes near to the carriageway and other types of cycle facilities.

8. ACKNOWLEDGEMENTS

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