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AAP-4274; No. of Pages 8
ARTICLE IN PRESS
Accident Analysis and Prevention xxx (2016) xxx–xxx
Contents lists available at ScienceDirect
Accident Analysis and Prevention
journal homepage: www.elsevier.com/locate/aap

Safe roundabouts for cyclists

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ARTICLE INFO

Article history:
Received 27 November 2015
Received in revised form 4 August 2016
Accepted 6 September 2016
Available online xxx

Keywords:
Roundabout
Design
Cyclist
Safety

ABSTRACT

May roundabouts be safer for cyclists than intersections? How are safe roundabouts designed? This paper tries to answer these questions on the basis of a before-after safety study of conversions of intersections to 255 single-lane roundabouts in Denmark. The before-after study accounts for long-term accident and injury trends and regression-to-the-mean effects. In order to relate safety effects for cyclists of various roundabout design features it is crucial to split the converted sites by speed limit, because safety effects for both cyclists and other road users of converting intersections to roundabouts depend heavily on speed limits on roads entering the converted sites. If speed limits are 70 km/h or higher then converting intersections to roundabouts have resulted in bicycle safety improvements in Denmark. Results show that diameter and height of central islands and type of bicycle facilities at single-lane roundabouts have considerable impacts on cyclists' safety. Central island diameters of 20–40 m are safer for cyclists than smaller or larger roundabouts. A central island, which middle is elevated 2 m or more above the circulating lane, is safer for cyclists than single-lane roundabouts with lower central islands. Single-lane roundabouts with separate cycle paths, where cyclists must yield to motorists entering or exiting the roundabout, are safer than roundabouts with cycle lanes. Single-lane roundabouts are safer for cyclists than intersections regardless of speed limits when these roundabouts have high central islands and/or separate cycle paths.

1. Introduction

Roundabouts as a type of intersection have become more and more popular in the past 2–4 decades. An example is that the number of roundabouts in Denmark has increased from about 50 in 1980 to 425 in 1995 and 1450 in 2010. Roundabouts are often established due to road safety concerns, but often roundabouts also work well in terms of traffic operations. The safety effects of converting intersections to roundabouts have been studied many times. Jensen (2013) made meta-analyses of 19 large before-after safety studies (Antoine, 2005; Brabander and de Vereeck, 2007; Brilon, 1997; Corben et al., 1990; Daniels et al., 2008; Fortuijn, 2005; Green, 1977; Gross et al., 2013; Jensen, 2012; Jørgensen, 1991; Jørgensen and Jørgensen, 1992, 1994; Lalani, 1975; Meuleners et al., 2005; van Minnen, 1990; Montonen, 2008; Newstead and Corben, 2001; Rodegerdts et al., 2007; Schoon and van Minnen, 1993; Tudge, 1990) of these conversions, see Table 1. The meta-analysis methodology has been described by Elvik (2001). Elvik et al. (2009) made similar meta-analyses of safety effects of roundabouts, but included both before-after safety studies and cross-sectional studies from before the year 2009, and found smaller safety effects than those shown in Table 1.

Table 1 shows that converting intersections to roundabouts reduce the number of accidents and injuries and reduce accident severity. But the safety effects for cyclists are not so good. The overall picture is that studies indicate that bicycle safety is worsened when intersections are converted to roundabouts. However, intersection design, roundabout design and other characteristics of converted sites influence safety effects for cyclists and other road users. This influence is considerable and safety effects shown in Table 1 should not be generalised due to excessive heterogeneity (Jensen, 2013).

Speed limits on the arms of roundabouts have a huge influence on safety effects of converting intersections to roundabouts, see Table 2. These conversions have overall not changed safety at sites in Danish urban areas with 40–50 km/h speed limits. However at the urban sites bicycle safety has worsened significantly, whereas the number of other accidents without cyclists involved has decreased significantly. At rural sites with 80 km/h speed limits safety has improved due to the conversions both for cyclists and other road users, but the percentage reduction in bicycle accidents is only about half the reduction in other accidents. Some roundabouts have arms, which are exit and entrance lanes to expressways and freeways, where the speed limit is 90–130 km/h. Here the

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http://dx.doi.org/10.1016/j.aap.2016.09.005
0001-4575/

Please cite this article in press as: Jensen, S.U., Safe roundabouts for cyclists. Accid. Anal. Prev. (2016), http://dx.doi.org/10.1016/j.aap.2016.09.005

Table 1
Results from meta-analyses of before-after safety studies of conversions of intersections to roundabouts (Jensen, 2013). Based on 25,324 accidents and 3634 injuries at converted sites.

Type of accident or injury	Best estimate of safety effect	95% confidence interval
Fatal accidents	−77%	−88%; −57%
Injury accidents	−59%	−65%; −52%
Property-damage-only accidents	−25%	−35%; −14%
All accidents	−43%	−48%; −37%
All injuries	−70%	−77%; −62%
Bicycle accidents	+22%	−10%; +66%

Table 2
Safety effects of converting intersections to roundabouts in Denmark split by highest speed limit on roundabout arms 100 m from the yield line (Jensen, 2012). In brackets are 95% confidence intervals. Results are based on 2497 accidents and 1328 injuries including 332 bicycle accidents at 332 converted sites.

Highest speed limit	All accidents	All injuries	Bicycle accidents	Other accidents
40–50 km/h	+1% [−13%; +18%]	−1% [−21%; +24%]	+109%[+59%; +174%]	−25%[−37%; −10%]
60 km/h	−13%[−31%; +10%]	−55%[−69%; −33%]	+70% [−5%; +204%]	−23% [−41%; −0%]
70 km/h	−32% [−54%; +2%]	−63%[−82%; −25%]	−59% [−91%; +99%]	−29% [−53%; +8%]
80 km/h	−43%[−50%; −35%]	−81%[−86%; −76%]	−21% [−55%; +40%]	−44%[−51%; −35%]
90–130 km/h	−67%[−84%; −31%]	−81%[−93%; −46%]	−31%[−94%; +660%]	−69%[−85%; −32%]

safety effects are even better compared to rural sites with 80 km/h speed limits.

Bicycle safety is also influenced by roundabout design. Brilon (1997) finds that marking cycle lanes next to the circulation increased bicycle accidents from 1 to 8 at three roundabouts. Schoon and van Minnen (1993) show that roundabouts with separate cycle paths are safer than roundabouts with marked cycle lanes or no bicycle facility at high traffic volumes. Brüde and Larsson (1999a) and Sakshaug et al. (2010) find that roundabouts with separate cycle paths and special cycle crossings are safer at higher traffic volumes than roundabouts without bicycle facilities. Daniels et al. (2009, 2010) find that roundabouts with marked cycle lanes next to the circulation are less safe for cyclists than roundabouts without bicycle facilities, and roundabouts with separate cycle paths are safer than roundabouts with no bicycle facilities. Jørgensen (1991) shows that the injury rate is lowest at roundabouts with cycle tracks next to the circulation and higher at roundabouts without bicycle facilities but highest at roundabouts with marked cycle lanes. Brüde and Larsson (1999a) find that the accident rate for cyclists is twice as high at small roundabouts, where the central island including truck apron is less than 20 m, compared to larger roundabouts. Hels and Møller (2007) and Turner et al. (2009) find that as motorists' entry and circulation speed at roundabouts increase then bicycle safety worsens.

This paper focuses on how the roundabout design influences bicycle safety. Not all roundabout design features are studied. Jensen (2012, 2013) found through several analyses that bicycle safety at roundabouts primarily is influenced by the design of the central island and bicycle facilities. Therefore these design features are in focus. The paper is based on a before-after safety study of conversions of intersections to 255 single-lane roundabouts in Denmark. A description of the converted sites is shown in Table 3. Here a cycle track is a bicycle facility with a kerb to the circulating lane, and where entering or exiting motor vehicles have to yield to circulating cyclists. There is a dividing verge between a separate cycle path and the circulating lane, and cyclists have to give way to motor vehicles at roundabout arms. In Table 3, grade-separation means that cyclists and pedestrians are to use paths in tunnels passing under arms of the roundabout. Results indicate whether or not it is possible to achieve safety improvements for cyclists when intersections are converted to roundabouts just by choosing a safe roundabout design.

2. Methodology

Safety effects of converting intersections to roundabouts are studied using an observational study methodology, where the observed number of accidents in a period after the conversions is compared to the expected number of accidents for the same period of time. The expected number of crashes is estimated on the basis of the number of accidents in a period before the conversions and corrections for confounding factors. The before period is five years long (from 1 January to 31 December) for all converted sites, whereas the after period is 1–5 years long. Usually it is good practice to use a methodology that accounts for three major possible biases in before-after safety studies; accident and injury trends, regression-to-the-mean effects and traffic volumes. Traffic volumes have not been measured before and after the conversions at most of the sites. Therefore, it is not possible to account for changes in traffic volumes.

A stepwise methodology is used. First, general comparison groups are used to account for accident and injury trends. Second, analyses of long-term accident and injury trends are made in order to check for abnormally high or low accident and injury counts, i.e. regression-to-the-mean, in the before period. The expected number of accidents in the after period is calculated based on Eq. (1):

$$A_{Expected} = A_{Before} \cdot C_{Trend} \cdot C_{RTM}, \quad (1)$$

where $A_{Expected}$ is the number of accidents expected to occur in the after period if conversions were not implemented, A_{Before} is the number of accidents that occurred in the before period, C_{Trend} and C_{RTM} are correction factors for accident trends and regression-to-the-mean.

2.1. Correction for general accident and injury trends

Accidents occurring in the 61 municipalities, where conversions took place, were used to set up general comparison groups. In 1985–2010 a total of 448,465 accidents and 176,373 injuries occurred in the general comparison groups excluding accidents and injuries at converted sites. Since general comparison groups were chosen instead of matched comparison groups, an effort was made in order to avoid consequences of larger differences between the general comparison groups and converted sites. Trends for the municipalities and different types of accidents and injuries of the general comparison groups were compared. Trends for intersection and segment accidents are very similar, and hence no need for sub-grouping. However, trends for different accident and injury