Accident Analysis and Prevention 42 (2010) 393–402

Contents lists available at ScienceDirect

Accident Analysis and Prevention

journal homepage: www.elsevier.com/locate/aap

Explaining variation in safety performance of roundabouts

Stijn Daniels[a,*], Tom Brijs[a,1], Erik Nuyts[b,2], Geert Wets[a,1]

[a] Hasselt University, Transportation Research Institute, Wetenschapspark 5 bus 6, 3590 Diepenbeek, Belgium
[b] PHL University College, Architecture, Art and Design Research Institute, Universitaire Campus Building E, 3590 Diepenbeek, Belgium

ARTICLE INFO

Article history:
Received 24 June 2009
Received in revised form 26 August 2009
Accepted 28 August 2009

Keywords:
Roundabout
Risk
Poisson
Gamma
Underdispersion
Regression
Crash
Safety

ABSTRACT

The conversion of an intersection into a roundabout has been proven to reduce generally the number of crashes with injuries or fatalities. However, evaluation studies frequently showed considerable individual differences in safety performance of roundabouts or particular groups of roundabouts. The main purpose in the present study was to explain the variance in safety performance of roundabouts through the use of state-of-the-art cross-sectional risk models based on crash data, traffic data and geometric data of a sample of 90 roundabouts in Flanders-Belgium. Poisson and gamma modelling techniques were used, the latter one since underdispersion in the crash data was observed. The results show that the variation in crash rates is relatively small and mainly driven by the traffic exposure. Vulnerable road users are more frequently than expected involved in crashes at roundabouts and roundabouts with cycle lanes are clearly performing worse than roundabouts with cycle paths. Confirmation is found for the existence of a safety in numbers-effect for bicyclists, moped riders and – with less certainty – for pedestrians at roundabouts.

1. Introduction

Roundabouts have become a common type of intersection design in many countries, although they are not yet used to the same extent everywhere. The number of roundabouts seems to increase steadily in countries and regions where they are already common while they are gaining popularity in regions where they were not applied in the past (Brilon and Vandehey, 1998; Brown, 1995; Pellecuer and St-Jacques, 2008; Rodegerdts et al., 2007; Thai Van and Balmefrezol, 2000). In a number of circumstances, roundabouts are assumed to be more beneficial than other intersection types, both in terms of traffic operations and traffic safety (Bird, 2001; Ogden, 1996; PIARC, 2003).

With respect to traffic safety, the conversion of an intersection into a roundabout has been proven to reduce the number of crashes with injuries or fatalities (e.g. in Elvik, 2003; Persaud et al., 2001). However, research has also shown that effects for particular user groups, such as bicyclists, are less favourable or even unfavourable (Daniels et al., 2009, 2008; Schoon and van Minnen, 1993).

Those general effects have typically been established by observational before- and after-studies and meta-analyses on the resulting estimates. Nevertheless, before- and after-studies frequently showed considerable differences in safety performance of particular roundabouts or particular groups of roundabouts. Obviously, chance factors might explain a part of the heterogeneity in the results. Crashes are rare events and from an analytical point of view, the number of crashes on the disaggregate level of particular locations is low and easily affected by pure chance elements. However, heterogeneity in the safety performance of intersections such as roundabouts might also be explained, at least partly, by some structural differences between locations. Several authors have suggested structural differences in roundabout safety performance according to exposure elements (traffic volume), but also according to some geometric features of roundabouts. Examples of explanatory models for crash counts at roundabouts are described in Brüde and Larsson (2000), Kennedy (2007) and Rodegerdts et al. (2007).

Some other authors attempted to fit models for particular user groups. Most of these models were related to bicyclists, probably since a weaker safety record for bicyclists at roundabouts has often been suggested (Brüde and Larsson, 1996, 2000; Hels and Orozova-Bekkevold, 2007; Layfield and Maycock, 1986; Turner et al., 2006).

The common purpose of all those attempts was to reveal some structural relationships between particular design or traffic characteristics on the one hand and the level of safety of roundabouts on the other hand. In most models, the investigated parameters were traffic volume and some geometric data, such as number of lanes, curvature, number of legs and the central island size. Generally, clear relationships were found between traffic volume (AADT) and crash frequencies. However, within the group of geometric data,

---

[*] Corresponding author. Tel.: +32 11 26 91 11; fax: +32 11 26 91 99.
E-mail addresses: stijn.daniels@uhasselt.be (S. Daniels), tom.brijs@uhasselt.be (T. Brijs), erik.nuyts@phl.be (E. Nuyts), geert.wets@uhasselt.be (G. Wets).

[1] Tel.: +32 11 26 91 11; fax: +32 11 26 91 99.

[2] Tel.: +32 11 24 92 13.

0001-4575/$ – see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.aap.2009.08.019

few variables showed a more or less structural relationship with the crash frequency.

Three reasons justify a renewed attempt to investigate explaining factors for safety at roundabouts. Firstly, the amount of research in this domain is all in all rather limited. Secondly, design guidelines for roundabouts differ from one country to another, which makes that research results from one country are not necessarily valid for another country and still some efforts are needed to gradually establish better universal knowledge on this topic. Thirdly, design guidelines have evolved over time and the newest roundabouts can be supposed to be designed according to more recent guidelines. Since design guidelines should have benefited from research results that have been found during the past decades, the design of modern roundabouts should therefore reflect improved insights in some elements that affect safety performance. Consequently, explaining factors for the crashes at roundabouts could have evolved over time as well.

The influence of design elements on safety is typically investigated by the fitting of cross-sectional risk models, i.e. models in which the variation in safety performance of a study sample is explained through the use of regression modelling techniques, nowadays most often Poisson regression and negative binomial regression.

The main purpose in the present study is to explain the variance in safety performance of roundabouts through the use of state-of-the-art cross-sectional risk models based on crash data, traffic data and geometric data of a sample of 90 roundabouts in Flanders-Belgium. The main target is to investigate which variables might explain a structural part of the variation in crash rates at roundabouts and to which extent the stated effects would correspond with earlier research results elsewhere. Moreover, an attempt is also made to add some variables that were not or not always included in prior analyses and that potentially could influence the safety level of roundabouts. In particular, this last element refers to some design characteristics of cycle facilities that are commonly used in a few European countries.

The remainder of the paper is organized as follows. The next section describes the data that were collected and the way it was done. Subsequently the analysis method is described and the results are provided. Finally the results are discussed and conclusions are drawn.

2. Data collection

90 roundabouts on regional roads in Flanders-Belgium were selected through a stratified random sample procedure (three or four roundabouts for each of the 28 administrative road districts) out of a database of the Roads and Traffic Agency. The included roundabouts were the same as in Daniels et al. (2009). For the purpose of the present study, each roundabout in the sample was visited and photographed, traffic counts were executed and additional geometric data were collected on the spot. Information on the construction year of the roundabout was available from the database. All investigated roundabouts were constructed between 1994 and 2000.

Collected data were a number of variables, expressed as dummies and describing some particular features of the roundabouts: a raised central island, a traversable truck apron (with, if present, the width of the apron), an oval shape of the central island, a gated roadway through the central island to accommodate oversized trucks, a bypass for right-turning traffic in one or more directions, and whether the roundabout was located inside or outside built-up area. Geometric data consisted also of the number of lanes on the roundabout, the road width, the central island diameter, the inscribed circle diameter (distance across the circle inscribed by the outer edge of the circulatory roadway) and the number of legs.

Furthermore some variables were collected in order to describe the present facilities for bicyclists and pedestrians. Four types of cycle facilities were distinguished: roundabouts with mixed traffic (motor vehicles and bicyclists use the same roadway), cycle lanes (lanes reserved for bicyclists close to the roadway), cycle paths (dedicated paths for bicyclists on a distance of more than 1 m from the roadway) and grade-separated roundabouts (with tunnels for bicyclists). The reader is referred to Daniels et al. (2009) for a detailed description of the different types of cycle facilities and some illustrations. For each roundabout the type of cycle facilities was recorded as well as the presence of line markings or small barriers between the roundabout and the cycle facility (in case of cycle lanes), the priority rules for bicyclists when crossing the exit/entry lanes (in case of separate cycle paths) and the pavement colour. Moreover, the width of the cycle facility – when present – was measured as well as its distance from the roadway. Finally, pedestrian facilities like the presence of a sidewalk around the roundabout, the presence of a zebra marking on the entry or exit lanes and – when present – the distance between the zebra marking and the outer edge of the circulatory roadway were measured. The collected variables are listed in Table 1.

No particular data were collected that enabled to determine the actual speeds at the roundabouts. Worth mentioning is that roundabouts in Flanders are generally constructed with perpendicular approaches in combination with central islands that are large enough to impose considerable lateral movements (deflections) on entering vehicles. Consequently, speeds of any types of vehicles at roundabouts are reduced considerably.

Traffic data were collected as follows: at each examined roundabout all entering traffic was counted by one or two observers during 1 h by day (between 8:00 and 18:00). Traffic modes were classified in light vehicles, heavy vehicles, motorcycles, mopeds, bicycles and pedestrians. Light vehicles comprised mainly private cars, but also minibuses and all kinds of vans. Heavy vehicles were trucks, trailers, busses and tractors. A particular reason for the distinction between motorcycles and mopeds is their different driving path through a roundabout. Mopeds are often allowed to use cycle facilities when these are present, while this is not the case for motorcycles. Furthermore, the engine power of mopeds is legally limited in such a way that no speeds higher than 45 km/h can be reached on level roads. Calibration counts were held on two roundabouts during one day (08:00–18:00).

The results of the calibration counts were used to calculate adjustment factors that brought all the hourly traffic counts to a common 10 h (08:00–18:00) level. Subsequently, the counts for private cars, heavy vehicles and motorcycles were added up in order to estimate a value for the Average Daily Traffic (ADT), representing the motorized, fast traffic. This approach enabled to obtain a useful classification of the sample of roundabouts according to their traffic volume, although this approach has obviously its limitations, see the discussion part. As a result, traffic volume data were available for six different traffic modes. Fig. 1 shows box-plots of the frequency of different traffic modes and the variability of the observed values.

The traffic counts were done during spring 2008 whereas the crash data for the examined roundabouts were spread over the period from the year after the construction year of the roundabout up to and including 2004, the last year of available data. In order to match the periods of the crash counts with the periods of the traffic counts another calibration procedure was followed. Firstly, the 'average roundabout year' was calculated per individual roundabout by considering the, rounded off, median year of available crash data per roundabout. For example, the 'average roundabout year' of a roundabout constructed in 1999 was 2002 (median of