Are Roundabouts really safer than Intersections?

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Abstract

The meeting place of roadways from different directions has a higher safety risk because of the large number of conflict points associated with it. Consequently, intersection crashes, in general, are more severe when compared to crashes reported at other places. The current trend in many developed countries is to replace regular intersections with roundabouts as a safety modification. However, in Switzerland only one study has been conducted in 1994 examining the safety of such roundabouts. We are currently unaware weather roundabouts increase safety or result in a greater confusion among drivers and other road users. To address this issue, this study focuses on comparing the safety at intersections and roundabouts in the canton of Zurich.

Keywords

Safety – Roundabouts – Intersections – Accidents – Canton of Zurich – Institute for Transport Planning and Systems – ETH Zurich

1. Introduction

Roundabouts are a common intersection type used in Switzerland. Looking at the documented roundabouts in the canton of Zurich, the first of its kind was built in 1968. By the end of 1995 a total of 44 roundabouts were registered. The current number lies at 200 roundabouts and it does not seem as if the number of new constructions or conversions from regular intersections would decrease in the near future (roundabout data of canton of Zurich). Despite this continuous increase in the number of roundabouts, very little research was done so far in Switzerland to assess its safety and operational effects. Studies performed in other countries reported that roundabouts are safer than regular intersections and in many cases also improve traffic operations (Elvik, 2003; Daniels et al., 2009; Gross et al., 2012). However, findings are different for different countries and also depend on the road users included. The purpose of this study is to compare the safety of roundabouts and regular intersections and to determine influential factors on accidents at these sites for Switzerland.

2. Literature Review

Many researchers studied the safety of intersections and often included roundabouts in their analysis. The following table summarizes some of these studies and their major findings concerning influential factors. It was used as a basis for this paper and gives a short overview of what was done so far in this research field. However, the following summary is not concluding. The influential distance describes the area used to determine accidents belonging to each intersection.

Table 1 Summary of literature review

Paper	Country of Survey	Number of Inter-sections	Method	Influential Factors		Influential Distance
				Regular Intersections	Roundabouts	
Chen et al. 2012	US and Italy	139 (US), 34 (Italy)	Bayesian Poisson-gamma model and zero-inflated Poisson model	-	Approach average speed (AAS)	-
Daniels et al., 2009	Belgium	90	Cross-sectional risk models (regression models)	-	Traffic exposure (cars, bicycles, mopeds), cycle lanes/cycle paths, (number of legs, roundabouts replacing signal controlled intersections)	100 m from centre of round-about
Elvik, 2003	Different non-US studies	-	Meta-analysis	-	Number of legs, previous type of traffic control, central island diameter	-
Flannery et al., 1999	United States	8	Before-after study	-	Traffic exposure, entry speed	-
Giaever, 1992	Norway	59 ra., 124 int.	Unknown	-	Number of legs	-
Gross et al., 2012	United States	28	Before-after study (empirical Bayes method) and cross-sectional analysis	-	Traffic volume, number of legs, urban or suburban roundabout	-
Hels et al., 2006	Denmark	88	Poisson regression and logistic regression analysis	-	Traffic volume (vehicles and bicycles), vehicle speed, age of roundabout, (number of legs)	-
Huber et al., 1994	Switzer-land	130	Before-after study	-	Number of legs, number of lanes at approaches, diameter	-

Hydén et al., 1999	Sweden	21	Before-after study	Speed level	Speed level	-
Saccomanno et al., 2008	-	-	Microscopic simulation model (VISSIM)	-	-	100 m up- and down-stream of inter-section
Turner et al., 2006	New Zealand	104	Generalised linear modelling methods	-	Circulating speed, capacity, visibility, number of lanes	-
Wang et al., 2006	United States	208	Generalized estimating equations (longitudinal study)	Traffic volume (ADTPL), appearance of heavy traffic, number of lanes, speed limit, area population, exclusive right-turn lane, partial left-turn protection phase	-	-
Wong et al., 2007	Hong Kong	262	Poisson regression and negative binomial regression	Road environment, curvature, presence of tram stops, number of pedestrian streams, traffic composition, lane width	-	-

These studies reported that conversions of intersections into roundabouts reduce crash frequencies. The effects on type of injury (severities) and type of road user however, are diverse. Generally, the factors influencing roundabout safety the most are traffic volume, approach speed and number of legs. However, different factors were analysed and influences of each of them are not consentaneously explained. Additionally, no consistent argumentation of safety of vulnerable road users (pedestrians and cyclists) at roundabouts is reported in these papers.

3. Structure

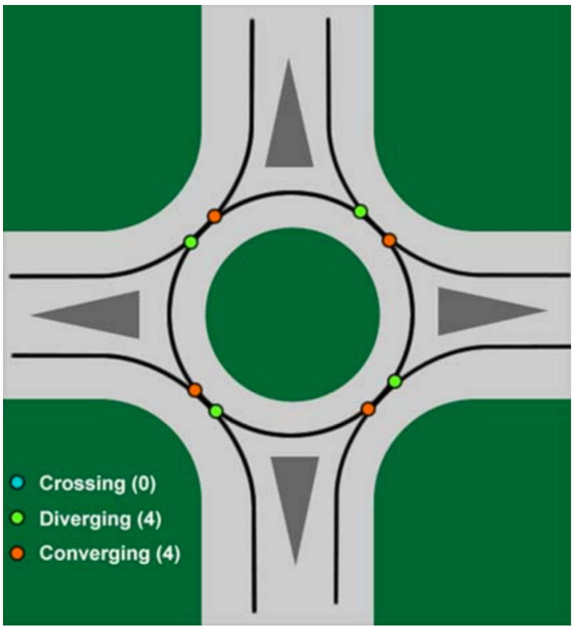
To compare the safety of regular intersections and roundabouts in Switzerland, this study used the data from the canton of Zurich. The methodology used for the analysis is explained in this section. They coincide with the structure of the subsequent chapters. Section 4 discusses the basic principles of regular intersections and roundabouts in Switzerland in general and with focus on Zurich. It also includes discussion on the norms in Switzerland as well as the guidelines for roundabouts in the canton of Zurich. To determine typical patterns in accidents at roundabouts and regular intersections, five year accident data of the canton of Zurich (from 2011 to 2015) was analysed and is included in section 5. Section 6 includes the analysis. Results are discussed in section 7 along with a short outlook on possible improvements of the analysis and further questions that need to be examined. Accidents at 181 roundabouts are compared with those at 199 similar intersections, including information about traffic volume and share of heavy vehicles as well as construction parameters such as number of legs, diameters, lane width in roundabouts or speeds towards the intersection. Factors influencing safety of roundabouts and intersections were identified and an attempt was made to answer the question if roundabouts are really safer than intersections.

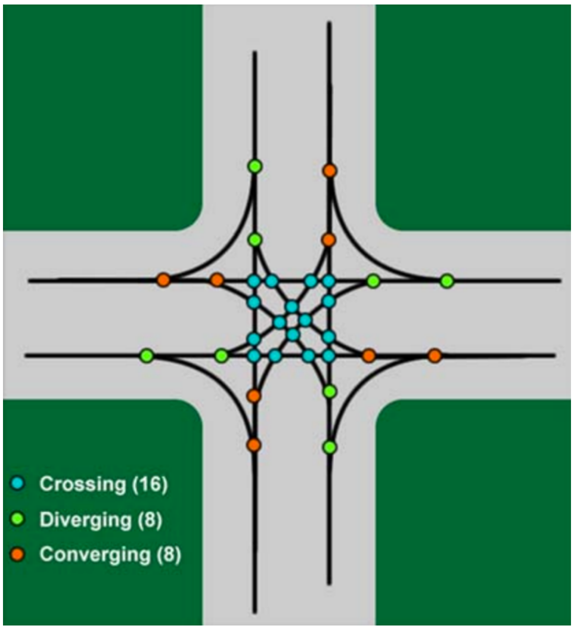
4. Regular Intersections versus Roundabouts

4.1 Basic Principles

According to the Federal Highway Administration of the United States, a modern roundabout is defined as “a compact circular intersection in which traffic flows counter-clockwise around a central island and entering traffic has to yield” (FHWA, 2007). This definition is transferable to roundabouts in Switzerland. The two concerned intersection types differ amongst others in traffic flow, signalization, design and number of conflict points. Conflict points are intercept or merge point of traffic streams. The higher the number of theoretical conflict points at a node, the higher the demand on the driver (number of reactions per time) and therefore the higher the probability that dangers arise (Müller, 2014). Figure 1 shows the number of theoretical conflict points at roundabouts and regular intersections with four legs. The figures are simplified, as there are no left or right-turn or multiple lanes at the intersection and only one lane at the roundabout. Still, it illustrates well that there is a much higher number of possible conflict points at regular intersections. Additionally, there are no left-turn or crossing movements at roundabouts. This has a big influence on the type of accidents.

Figure 1 Conflict points between vehicles





Source: (FHWA, 2007)

4.2 Roundabouts in Switzerland / Norms

The Swiss road traffic law only gives few information about roundabouts and intersections in general. The traffic regulations act (VRV) mentions the following points about roundabouts. Before entering, vehicles have to reduce their speed and yield to vehicles coming from the left. Blinking in the roundabout is not necessary, unless a lane change happens. Leaving the roundabouts has to be shown by blinking right. In roundabouts, bicycles do not have to drive on the right side of the street (VRV, 2017, Art. 41b). Design and dimensioning of regular intersections and roundabouts are based upon Swiss Standards (SN) that are published by VSS (Schweizerischer Verband der Strassen- und Verkehrsfachleute).

Roundabouts with diameters larger than 50 m have at least two lanes in it. They are mainly used as a connection to freeways (SN 640 251, 1997). Smaller roundabouts are divided into three categories that are defined as follows (SN 640 263, 1999):

Mini roundabout: Outer diameter between 14 and 26 m, traversable central island, mainly on settlement orientated streets.

Small roundabout: Outer diameter between 26 and 40 m, non-traversable central island, mainly on traffic orientated streets.

Large roundabout: Outer diameter > 40 m.

Small roundabouts are the most common ones in Switzerland (Müller, 2014). The following table summarizes some design recommendations for this roundabout type according to SN 640 263. Parameters used in the table are according to figure 2.

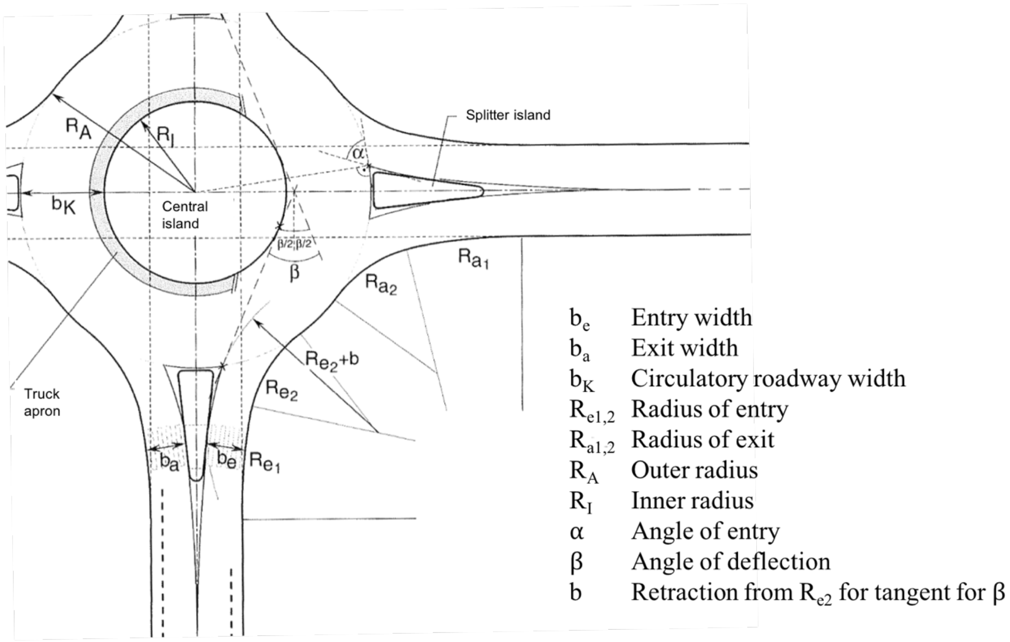
Table 2 Design recommendation according to SN 640 263

Location	Value	Comments
Entry		
Entry width b_e:		
1 lane	3.0 – 3.5 m	Measured at zebra crossing or 7 m from roundabout, entry velocity < 30 km/h
2 lanes	< 6.0 m	
Radius of entry $R_{e1,2}$:		
R_{e1}	$\sim 5 \cdot R_{e2}$	Normally designed as a dyadic three-centre curve
R_{e2} urban (“innerorts”)	~ 10.0 m	
R_{e2} suburban (“ausserorts”)	~ 12.0 m	
Angle of entry α:	80 – 90 gon	If $\alpha < 70$ gon then β has to be > 45 gon
Splitter island:		
Width at roundabout	> 3 m	Funnel-shaped
Roundabout		
Outer diameter 2 R_A:		

Within populated areas	26 – 35 m	Normally circular shape, max. relation of width to length 1:1.15
Outside populated areas	30 – 40 m	
Circulatory roadway width b_K:		Depends on the outer diameter and the standard vehicle, width above 5.5 m should be constructed as truck apron
Angle of deflection β:	> 45 gon	
Slopes:	2.5 – 5 %	
Exit		
Exit width b_a:		
Without bicycle lane	3.5 – 4.5 m	Measured at zebra crossing or 7 m from roundabout, entry velocity < 35 km/h, no exits with more than one lane
With bicycle lane	4 – 4.5 m	
Radius of exit $R_{a1,2}$:		
R_{a1}	~ $5 \cdot R_{a2}$	Normally designed as a dyadic three-centre curve
R_{a2} urban ("innerorts")	~ 12.0 m	
R_{a2} suburban ("ausserorts")	~ 14.0 m	

Source: (SN 640 263, 2000), translated

Figure 2 Parameters small roundabout



Source: (SN 640 263, 2000), translated

SN 640 263 differentiates between three sight distances. The *stopping sight distance* has to be guaranteed on the approaching lanes as well as in the roundabout. The *sight distance in the node* depends on the velocity of the vehicle in the roundabout, which again depends on the angle of deflection. The *visibility through the roundabout* should be prevented by plantings, other constructions on the central island or through an elevation, so that drivers focus on vehicles coming from the left and that the central island is well visible (SN 640 263, 2000). No bicycle lanes should be marked in the roundabout, since the speed for vehicles in the roundabout is about the same as for bicycles. However, this only holds true for outer diameters smaller than 35 m. Larger roundabouts with multiple lanes are not suitable for a mixed road use (Müller, 2014).

4.3 Guidelines for Roundabouts in the canton of Zurich

The guidelines for roundabouts in the canon of Zurich were developed in 2008. They list mandatory elements and dimensions for roundabouts with one circulatory roadway on national streets and are mainly based on the above mentioned Swiss Standards. Additional things not included in the VSS norms are summarized in the following section (Kreiselrichtlinie Kanton Zürich, 2008).

- The outer diameter shall be as large as possible.
- Due to negative experiences with truck aprons, they should not be built with new roundabouts. Instead, the circulatory lane width has to be bigger.
- Legs should be oriented centrically toward the roundabout.
- Radius of entry R_e = 12 m and radius of exit R_a = 15 m.
- Width of splitter island should be 2.5 m if bicycles can cross. They should be placed 5 m from the roundabout. In exceptional cases they can be replaced by markings.
- Pavement can be concrete or asphalt.
- Sidewalks adjoining roundabouts should have a minimal width of 2.5 m.

5. Accident Data of canton of Zurich – Total Numbers

In Switzerland the Federal Roads Office (FEDRO, in German: ASTRA) is responsible for evaluations of road traffic accidents in the whole country. Together with the cantons it operates an information system to record and evaluate traffic accidents (SVG, Art. 89i). All accidents that are recorded by the police should directly be added to the system by the responsible body of the canton. Road traffic accidents that are recorded by the military police are added to the system by the Federal Department of Defense Civil, Protection and Sport (DDPS, in German: VBS) (SVUR, Art. 8-9). Information about persons involved, vehicles and the accident location can be imported into the information system.

FEDRO provided us with road traffic accident data of Switzerland from 2011 to 2015. In the following sections, accidents in Zurich with a given accident site of roundabout or intersection were analysed by looking at total numbers. The aim was to find typical patterns.

5.1 Overview

From 2011 to 2015 a total of 8'330 accidents were reported at roundabouts and intersections in the canton of Zurich. Only 17.7 % of them occurred at roundabouts. Figure 3 shows the total numbers of accidents per year and site. Table 3 summarizes the averages and standard deviations of total numbers of accidents per year and site. In each year, the total number of accidents at roundabouts and intersections in the canton of Zurich is between 3.0 % and 3.5 % of all reported accidents in Switzerland at the considered sites.

Figure 3 Total numbers of accidents per year and site

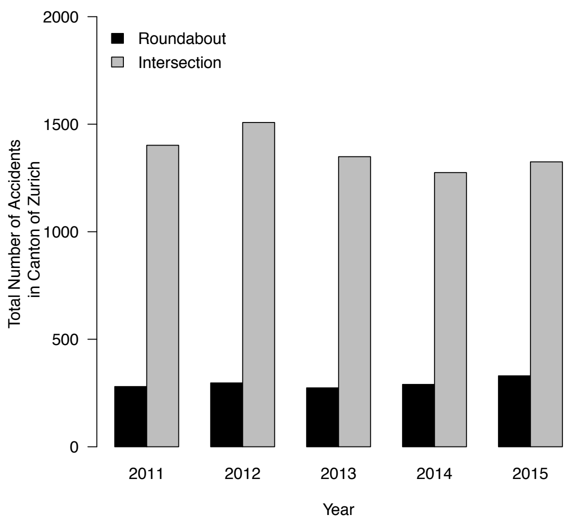


Table 3 Accidents per year

Site	Total number of accidents per year and site Average	Standard Deviation
Roundabout	294	22.0
Regular intersection	1’372	88.8

5.2 Cause of Accident

Looking at the percentage share of main accident reasons at roundabouts and regular intersections over the whole period, it can be found that the main reason for accidents at roundabouts is the disregard of the no-right-of-way sign (30.7 %), followed by momentary inattentiveness (18.3 %). At intersections, momentary inattentiveness seems to be the biggest reason for accidents (13.6 %), but also disregard of no-right-of-way (9.5 %) and red traffic lights (7.1 %) are other common reasons.

5.3 Type of Accident

The main accident type at roundabouts is the collision between a vehicle in the roundabout and the one entering it (31.6 %). This matches with the main crash reason - disregarding the ROW sign. The second most accident type is rear-end collision (17.2 %). At intersections rear end accidents are most frequently reported (14.4 %) followed by road crossing accidents (13.0 %). The percentage of self-inflicted accidents seems to be higher at roundabouts than at regular intersections.

5.4 Severity of Injuries

73.7 % of all accidents at roundabouts were found to be property damage only (PDO) accidents. At intersections, the share is comparable. 68.8 % of all accidents were PDO. The number of injured persons and severities of injuries are summarized in table 4. It shows that the percentage of injured persons are a slightly higher at intersections when compared to roundabouts. Concerning the severities of injuries, no big differences can be found.

Table 4 Severity of injuries

Site	Roundabouts	Regular Intersections
Total number of accidents with		
- dead people	3	13
- badly/considerably injured people	63	378
- slightly injured people	321	1'749
Total number of persons involved	3'139	15'888
Total number of persons injured	408	2'553
Persons injured [%]	13.0	16.1
Number of persons		
- dead	3 (0.1 %)	13 (0.1 %)
- badly/considerably injured	64 (2.0 %)	400 (2.5 %)
- slightly injured	341 (10.9 %)	1'749 (11.0%)

5.5 Objects Involved

Concerning objects (motorized vehicles, bicycles and pedestrians) involved in accidents, a total of 2'576 was recorded at roundabouts and 12'797 at intersections. Out of all objects involved in crashes at roundabouts only 59 (2.3 %) were pedestrians. At intersections a similar share of 2.6 % can be found. Not surprisingly, the main objects involved are cars up to 3.5 t and 9 seats (68.3 % at roundabouts, 70.4 % at intersections). The share of bicycles involved seems to be slightly higher at roundabouts with 8.2 % compared to 5.6 % at regular intersections. The same holds true for motorcycles up to 25 kW. However, the difference (0.3%) is very small, if not negligible.

5.6 Visibility

At roundabouts only 3 out of 1'471 accidents happened due to visibility issues. In one case bad overview due to fixed constructions was the reason. One crash happened because of a bad overview due to planting or mobile constructions and one due to another influence of the visibility of the driver.

Also intersections do not seem to have visibility problems. Out of 6'859 accidents only 13 had visibility issues recorded as the reason for the crash. 7 accidents happened because of a bad overview due to planting or mobile constructions, 3 because of a bad overview due to fixed constructions and another 3 because the visibility was influenced by persons or goods.

5.7 Additional Factors

Street condition and speed limit were also analysed to eventually find influential factors of accidents at roundabouts and intersections. However, no big surprises were found. At roundabouts 65.9 % of all accidents happened when it was dry. At intersections this was the case for 73.3 % of all crashes. Concerning speed limit, in 70.8 % of all crashes at roundabouts and 72.8 % at intersections the speed limit was 50 km/h. This makes sense, as the speed limit is normally 50 km/h in urban areas in Switzerland, which is also where most roundabouts and intersections are found.

6. Comparison of Accidents at Roundabouts and regular Intersections

6.1 Data

The canton of Zurich provided data of 200 roundabouts on regional roads, including information about year of construction, design parameters such as e.g. number of legs, diameters or lane widths, traffic volumes and speed limits. To get more information such as the number of legs towards the roundabout, the geographical information system of the canton of Zurich (www.gis.zh.ch, Orthofoto ZH 2014 – 2016) was consulted. In the range of this work it was not possible to physically visit the roundabouts. It is generally assumed that roundabouts in Switzerland have splitter islands as well as zebra crossings for pedestrians in each leg. Two roundabouts in the canton have different number of lanes in different parts of the roundabout. These, as well as very oval-shaped roundabouts were excluded from the analysis. Additionally, 5 roundabouts were excluded as some of the important information was not available for those roundabouts. Since accident data covers the years 2011 – 2015 roundabouts built in or after 2015 were also sorted out. Finally, 181 roundabouts were included in the analysis.

Data for 200 comparable intersections were prepared in a second step. The intersections were chosen randomly, but in the same area like the roundabouts. With the geographical information system of the canton of Zurich, the number of legs and lanes towards the intersection as well as the signal control was defined. Traffic volumes and speed limits were available from the provided data of the canton of Zurich. Since one intersection only had the traffic volume given on one of its legs, it was excluded for the analysis. 199 comparable intersections remained.

Traffic volumes at roundabouts and regular intersections were evaluated by adding up the annual average daily traffic (AADT) of 2011 of all vehicles (cars, trucks, vans) on all legs towards the intersection. To get the percentage share of heavy vehicles, the sum of AADT of trucks and vans on all legs was additionally calculated. Concerning bicycles and pedestrians, the canton of Zurich does not simulate traffic volume networks for these road users (Gesamtverkehrsmodell, 2011).

Accident data for the years 2011 to 2015 were provided by FEDRO (see chapter 5). It was linked to the intersections with the GIS-system ArcMap via the X- and Y-coordinates of the crashes. For the analysis all accidents within a distance of 100 m of the intersection centre were included. Accidents at roads crossings (roads crossing at different levels) and crashes at parking areas away from the street were excluded manually. Also accidents that happened before the roundabout was built were not included. Concerning accident reasons and types, the main ones determined in chapter 5 were extracted for the analysis. A total of 1’939 accidents were analysed at roundabouts and 2’298 at regular intersections. It has to be kept in mind, that more accidents are analysed compared to chapter 5, since crashes are only reported with accident site “roundabout” when they effectively happen in it. This paper also includes crashes happening away, but still due to the roundabout.

All data used for the following safety analysis is summarized in table 5.

Table 5 Description of dependent and explanatory variables

	Descriptive Statistics	
Variable, ABBREVIATION (categories)	Roundabout	Regular Intersection
Year of construction, YEAR (0 = before 1990; 1 = 1990 – 1995; 2 = 1996 – 1999; 3 = 2000 – 2010; 4 = after 2010)	0: 5; 1: 38; 2: 29; 3: 91; 4: 18	
Concrete pavement, CONC (0 = No; 1= Yes)	0: 122; 1: 59	
Number of legs to intersection, LEGS (0 = 3 or less; 1 = 4 or more)	0: 73; 1: 108	0: 148; 1: 51
Lane width in roundabout, WIDTH (0 = < 7m; 1 = ≥ 7m)	0: 135; 1: 46	
Outer diameter, DIAM (0 = < 14m; 1 = 14 – 26m; 2 = 27 – 40m; 3 = > 40m)	0: 0; 1: 45; 2: 135; 3: 1	
Annual average daily traffic, AADT entering	Mean: 11’740; S.D.: 5’731	Mean: 11’071; S.D.: 7’268
Percentage AADT of heavy vehicles, HVEH [%]	Mean: 8.7; S.D.: 4.3	Mean: 9.9; S.D.: 5.1
Number of lanes in legs toward intersection, LANES (0 = all have 1 lane; 1: one or more legs have 2 lanes)	0: 179; 1: 2	0: 89; 1: 110
Curvature ahead of intersection, CURVE (0 = No; 1 = Yes)	0: 139; 1: 42	0: 127; 1: 72
Speed limit, SPEED [km/h]	Mean: 56.7; S.D.: 10.8	Mean: 56.8; S.D.: 11.6
Signal control, SIGNAL (0 = Stop; 1 = No-ROW; 2 = Traffic light; 3 = Priority from right; 4 = 0 and 1)		0: 18; 1: 118; 2: 47; 3: 8; 4: 8
Total number of accidents between 2011 and 2015 at each intersection, TOT_ACC	Mean: 10.7; S.D.: 6.9; range: [0;39]; total: 1’939	Mean: 11.5; S.D.: 9.8; range [0;52]; total: 2’298
Total number of accidents with fatally or severely injured people at each intersection, FATSEV	Mean: 0.5; S.D.: 0.8; range: [0;4]; total: 89	Mean: 0.5; S.D.: 0.8; range: [0;4]; total: 91
Total number of accidents with slightly injured people at each intersection, SLIGHTLY	Mean: 2.2; S.D.: 2.0; range: [0;10]; total: 402	Mean: 2.2; S.D.: 2.5; range: [0;14]; total: 438
Total number of accidents with property damage only at each intersection, PDO	Mean: 8.0; S.D.: 5.5; range: [0;29]; total: 1’448	Mean: 8.9; S.D.: 7.9; range: [0;45]; total: 1’769
Total number of accidents with reason “Disregard of No-ROW” at each intersection, ROW	Mean: 2.2; S.D.: 2.3; range: [0;12]; total: 398	Mean: 1.2; S.D.: 2.0; range: [0;15]; total: 232
Total number of accidents with reason “Inattentiveness” at each intersection, INAT	Mean: 2.1; S.D.: 2.4; range: [0;14]; total: 379	Mean: 2.4; S.D.: 3.1; range: [0;18]; total: 473
Total number of accidents with reason “Disregard of red traffic light” at each intersection, TL	(reason for 1 accident: TL after exit within 100 m)	Mean: 0.4; S.D.: 1.6; range: [0;16]; total: 86
Total number of accidents with reason “Disregard of stop sign” at each intersection, STOP	(reason for 4 accidents at 3 roundabouts: entering side streets within 100 m)	Mean: 0.4; S.D.: 1.4; range: [0;14]; total: 75
Total number of accidents with reason “Too small gap to vehicle ahead” at each intersection, GAP	Mean: 0.3; S.D.: 0.7; range: [0;5]; total: 61	Mean: 0.5; S.D.: 1.0; range: [0;6]; total: 101

Total number of accidents with reason "Disregard of priority from the right" at each intersection, PFR	reason for 9 accidents at 6 roundabouts: entering side streets within 100 m)	Mean: 0.1; S.D.: 0.4; range: [0;4]; total: 13
Total number of accidents with type "Rear-end" at each intersection, REND	Mean: 1.7; S.D.: 2.2; range: [0;12]; total: 306	Mean: 2.1; S.D.: 3.0; range: [0;16]; total: 413
Total number of accidents with type "turning into a road" at each intersection, TURN	Mean: 2.1; S.D.: 2.2; range: [0;10]; total: 383	Mean: 0.3; S.D.: 0.8; range: [0;7]; total: 67
Total number of accidents with type "self-inflicted or skidding" at each intersection, SELF	Mean: 3.3; S.D.: 2.3; range: [0;12]; total: 591	Mean: 2.6; S.D.: 2.4; range: [0;13]; total: 519
Total number of objects involved in accidents between 2011 and 2015 at each intersection, TOT_OBJ	Mean: 18.2; S.D.: 12.6; range: [0;78]; total: 3'291	Mean: 20.6; S.D.: 18.8; range: [0;99]; total: 4'103
Total number of bicycles involved at each intersection, BICYCLE	Mean: 1.5; S.D.: 1.7; range: [0;9]; total: 263	Mean: 0.8; S.D.: 1.1; range: [0;5]; 167
Total number of pedestrians involved at each intersection, PED	Mean: 0.5; S.D.: 1.1; range: [0;8]; total: 98	Mean: 0.4; S.D.: 0.9; range: [0;6]; total: 88
Total number of motorcycles involved at each intersection, MOTORC	Mean: 1.2; S.D.: 1.3; range: [0;6]; total: 219	Mean: 1.0; S.D.: 1.1; range: [0;4]; total: 202

Table 6 shows the percentage share of type of road users involved in all accidents. 100 % describe all objects involved in all crashes. Since the share of trams and trains involved in crashes is very small, the difference to 100 % can be interpreted as the highest share which understandably belongs to cars. Comparing the total number of accidents between 2011 and 2015 at intersections with the AADT on it, values according to table 7 can be found.

Table 6 Percentage share of objects involved

	Roundabout	Regular Intersection
Pedestrians	3.0 %	2.1 %
Bicycles	8.0 %	4.1 %
Motorcycles	6.7 %	4.9 %

Table 7 Accidents/1'000 AADT

	Roundabout	Regular Intersection
Average	1.0	1.2
Standard deviation	0.9	1.1
Range	[0;10.8]	[0;8.1]

6.2 Methodology

Correlation between Variables

As a first step the correlation matrix between explanatory variables was inspected. Firstly, for the whole data set including all independent variables that were given for both, roundabouts as well as for regular intersections. Afterwards, for explanatory variables of roundabouts and regular intersections separately. In case of strong correlation ($\geq$ 0.7), one of the two correlating variables would have had to be eliminated. To evaluate the correlation matrix and for all further analysis, the open source statistical program R was used.

Count Models

Using the available data of traffic volumes and geometry, count regression models were fitted. The total number of recorded accidents or objects involved during the years 2011 until 2015 at each intersection was used as the dependent variable. In the past, accidents at intersections were often modelled with Poisson or negative binomial regression models. Overdispersion, when the mean is significantly smaller than the variance, is a common issue when analysing crash data. In several researches it was found that negative binomial regression models fit the data better when it is overdispersed (e.g. Lord et al., 2005). Otherwise, Poisson models should be used. Overdispersion could also be found in the data analysed in this paper. This is why negative binomial regression models were fit to compare safety at roundabouts and regular intersections and to explain the number of accidents at these sites. The formula for the negative binomial regression can be derived from the Poisson model as e.g. shown in Chang, 2005. In a first step the whole data set was used to see if certain patterns can be detected and to overall compare safety at roundabouts and regular intersections. To do this an indicator variable RA_INT was introduced (0 = regular intersection, 1 = roundabout). In a second step, the negative binomial regression model was applied to find influential factors on number of crashes at both analysed sites. The goodness-of-fit was evaluated with the Akaike Information Criterion (AIC), where the lowest AIC value represents the best fitting model.

Identification of Influential Factors

With the negative binomial regression model, parameters of all independent variables were estimated (β_i) for roundabouts and regular intersections separately. However, only parameters with values significantly different from zero ($p \leq 0.1$) were analysed. Their influence on e.g. the total number of crashes can then be evaluated using the following formula (Sasidharan et al., 2013):

$$\text{Influence on dependent variable} = \exp(\beta_i) - 1 \quad (1)$$

6.3 Results

Considering the whole data set with the independent variables for roundabouts and regular intersections, no significant correlations (≥ 0.7) were found. The same holds true when looking at the correlation between the independent variables at roundabouts and regular intersections separately. Therefore, all explanatory variables were used in the count models.

Table 8 summarizes the results of the comparison of safety at roundabouts and regular intersections. However, except for TOT_ACC only the ones with an estimated parameter significantly different from zero are listed. Accident reasons TL, STOP and PFR were not analysed, since they hardly appear in the roundabout data. The dispersion parameter is calculated as the division of the variance by the mean of the dependent variable. A value > 1 indicates overdispersion. Therefore, negative-binomial regression model was used for the analysis.

Table 8 Estimation of safety at roundabouts and regular intersections

Accidents / Objects	Estimated Parameter (RA_INT)	Significance	AIC	Dispersion
TOT_ACC	-0.03		2’367.3	6.6
ROW	0.54	**	1’287.1	2.9
TURN	1.84	***	990.4	2.9
SELF	0.43	***	1’583.3	1.9
BICYCLE	0.47	**	1’080.0	1.8

*** p < 0.001, ** p < 0.01, * p < 0.05, ‘.’ p < 0.1

With an estimated parameter of -0.03, the model for all crashes indicates very slightly that less accidents occur when the intersection is a roundabout. However, not at a significant level. Since TURN represents the main accident type at roundabouts, it is not surprising that the estimated parameter is significantly positive. The same holds true for the accident reason ROW. The estimated parameters for the number of self-inflicted accidents (SELF) and the number of bicycles involved (BICYCLE) are of bigger interest. The model shows that more self-inflicted crashes happen at roundabouts and that significantly more bicycles seem to be involved in accidents at this site.

The results of the parameter estimation for independent variables of accidents at roundabouts are provided in table 9. However, only the parameters significantly different from zero are listed. The dispersion parameter again shows that the negative-binomial regression model can be used. To avoid small parameter estimates for AADT, the logarithm of it was used in the analysis.

Table 9 Estimated parameters β_i of independent variables for roundabouts

Accidents / Objects	LN(AADT)	HVEH	SPEED	CURVE	LEGS	DIAM	AIC	Dispersion
TOT_ACC	0.70 ***	-1.62 .					1’114.6	4.4
FATSEV	0.80 **		-0.03 *				337.7	1.3
SLIGHTLY	0.58 ***	-4.57 **		-0.40 *			701.4	1.9
PDO	0.74 ***						1’025.2	3.8
ROW	0.68 ***	-4.00 *		-0.31 .	0.53 **		705.1	2.5
INAT	1.13 ***	-3.08 .		-0.31 .			660.8	2.8
GAP	1.49 ***			-0.73 .			261.6	1.4
REND	1.52 ***	-4.45 *					584.2	2.9
TURN	0.57 **	-4.64 *		-0.40 *	0.40 *		699.1	2.3
SELF	0.38 ***		0.01 .				775.1	1.6
BICYCLE	0.48 **	-8.30 ***	-0.02 .	-0.40 .			593.1	1.9
PED	0.65 *		-0.11 **	-0.83 *	-0.51 .	-0.85 **	332.2	2.3
MOTORC	0.54 ***						536.9	1.3

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, ‘.’ $p < 0.1$

The most significant exposure variable is AADT, which has a positive effect on the number of crashes at roundabouts. The percentage share of heavy vehicles as well as the speed limit at the roundabout and curvature ahead seem to affect crashes at roundabouts negatively (e.g. the higher the share of heavy vehicles, the smaller the number of accidents or road users involved). However, not in all of the categories regarded. The number of legs has a positive effect on accidents due to not giving right-of-way and the accident type of turning into a road. This is the main reason and type of crashes at roundabouts. Concerning accidents with pedestrians involved, the number of legs seems to have a negative effect. Pedestrians might be paying more attention to roundabouts with more number of legs and high AADT. The outer diameter is the only geometric variable that appears to have an influence on accidents at roundabouts. Even if the effect is only significant for accidents with pedestrians involved. This might be because drivers pay more attention at big roundabouts with more lanes / pedestrians using the channelizing island to finish the crossing.

Table 10 summarizes the parameter estimation of the independent variables for regular intersections. In this case also, the use of the negative-binomial model is valid and only the parameters significantly different from zero are shown.

Table 10 Estimated parameters β_i of independent variables for regular intersections

Accidents / Objects	LN(AADT)	SPEED	LEGS	LANES	SIGNAL	AIC	Dispersion
TOT_ACC	0.68 ***	-0.02 ***	0.27 **	0.19 *		1’256.5	8.4
FATSEV	0.32 .		0.54 *			366.1	1.3
SLIGHTLY	0.90 ***	-0.02 ***	0.31 *			722.5	2.8
PDO	0.65 ***	-0.02 ***	0.25 *	0.21 *		1’175.8	7.1
BICYCLE	0.42 **	-0.05 ***			-0.33 **	483.1	1.4
PED	0.73 **	-0.14 ***			-0.34 .	321.1	1.9
MOTORC	0.55 ***		0.36 *			531.2	1.2

*** p < 0.001, ** p < 0.01, * p < 0.05, ‘.’ p < 0.1

Since the focus is given to roundabouts in this paper, it is not specifically looked at the influences on crashes at intersections concerning their signalization. However, the influences on the total number of accidents, accidents with different severities and the different road users involved are shown. Again the AADT is a significant exposure variable. Also the speed limit shows a rather consistent negative effect on accidents. This means that the higher the speed limit, the fewer accidents happen or the less bicycles and pedestrians are involved. Possible reasons are that the speed limit is higher at locations away from residential and commercial activities. Therefore, there is less exposure for cyclists and pedestrians. Additionally, the number of possible conflict points for vehicles in highways with higher speed limits is smaller. The number of legs has a positive effect on the number of crashes, while the number of lanes only affects it positively looking at all or only PDO accidents.

7. Discussion

To be able to analyse the data set, many assumptions and simplifications had to be made that influence the results and should be kept in mind when interpreting them. Firstly, one has to consider that accidents are rather rare incidents. Therefore, chance factors that influence the number of crashes at a certain location should not be forgotten. Then there is the problem of underreporting. In Switzerland accidents only have to be reported to the police if a person got hurt, if a danger cannot be removed immediately or if a person wishes to report the accident (MISTRA, 2015). In all other cases the crashes are probably not reported and therefore not registered in the system. This is especially problematic for less severe accidents or accidents with property damage only. They are probably underestimated in this data set and therefore bias the crash data. The registered and in this paper regarded roundabouts cover almost the whole area of the canton of Zurich. Even though, regular intersections were chosen close to these roundabouts with comparable AADT, number of legs…., they were chosen randomly. The study does not evaluate how representative the chosen regular intersections effectively are.

The general understanding that roundabouts are safer than regular intersections could not be illustrated with the elaborated data set. Even though, the estimated parameter indicates a trend towards this assumption, it would be over-interpreting of data. However, the analysis supports the before assumed effect (Hels et el., 2006) that roundabouts are a potential risk for cyclists. Also concerning accident types, it is interesting to find that more self-inflicted or skidding crashes happen at roundabouts. This was already suggested in chapter 5 and seems to be an interesting topic for further research. Concerning the estimated parameters describing the number of accidents and objects involved, the following conclusions can be drawn. It is not surprising that the traffic volume influences the number of accidents positively. This has been shown in many researches before (e.g. Daniels et al., 2010, Hels et al., 2006) and is again illustrated for regular intersections as well as for roundabouts in this paper. The negative effect of share of heavy vehicles might be explained similarly as the negative estimates for speed limits, since these shares are low in urban areas where most of the crashes happen. Concerning the speed limit it could additionally be assumed that speed limit and roundabout diameter correlate. A higher speed limit means that the diameter has to be larger and therefore maybe less accidents happen. However, these are only assumptions since neither the correlation nor the influence of diameter on number of accidents could be shown here. The main reason is probably the small variation of different roundabout diameters in this data set.

This study is the first of its kind conducted in this range in Switzerland. Even though, data from only one canton was used in the study, it gives some good information about general safety at intersections and influential factors on accidents at roundabouts in Switzerland.

Some results need more investigation in future research while others support findings of earlier studies. A next step could be to find a relationship between accident influence distance and different roadway geometrics and traffic conditions for roundabouts and regular intersections. Another aim would be to evaluate crash data at roundabouts of more cantons and therefore include more explanatory variables through a higher variability of roundabout geometrics (e.g. number of lanes in the roundabout, special lanes/paths for bicycles, bicycle volumes, oval-shaped roundabouts etc.).

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