

1 **SAFETY EVALUATION OF CZECH ROUNDABOUTS**

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26 **ABSTRACT**

27 Roundabouts around the world are often seen as a beneficial measure for intersection safety. While  
28 also in the Czech Republic their numbers have grown in recent decade, their safety impact has not  
29 been fully studied still. At the same time Czech roundabouts have been sometimes seen as unpopular,  
30 including doubts about their benefits. This situation inspired the authors to investigate three general  
31 hypotheses related to Czech roundabouts: (1) Roundabouts are safer than traditional intersections, (2)  
32 Roundabout conversions are beneficial for safety, and (3) Czech roundabout safety performance is  
33 comparable to other countries. The paper provides the information and analyses in order to test these  
34 hypotheses. The final results are mixed: compared to traditional intersections safety at roundabouts has  
35 been gradually improving in recent years and before-after study of urban roundabout conversions  
36 yielded positive crash modification factors; on the other hand Czech roundabout expected crash  
37 frequencies are higher compared to other European countries. Possible reasons and future directions  
38 are listed and discussed.

39 **1 INTRODUCTION**

40 In general road network consists of intersections and road sections between them. At intersections  
41 road users may change their paths in order to get to their destinations. Intersections are thus crucial for  
42 the road network mobility performance. However there is number of conflict points between road user  
43 paths at each intersection, whose number is dictated by intersection design: while 4-leg intersection  
44 features 32 conflict points, a 3-leg has only 9. This is likely to increase the intersection crash  
45 performance: according to an international review (1), crash frequencies are in general higher at 4-leg  
46 than at 3-leg ones.

47 This is why intersections are in general considered the most critical element of the road  
48 network (2) and one of the most complex traffic situations that road users encounter (3). They are the  
49 places of high crash concentration, despite the relatively short time spent travelling through them (4).  
50 In most countries between 40 and 60% of total crashes occur at intersections (5). In the Czech  
51 Republic following figures from 2013 may be provided:

- 52 – 18,549 of 84,398 crashes happened at intersections, i.e. approximately 22% of crashes.
- 53 – These crashes resulted in almost 20% of total fatalities (114 out of 583 in total).

54 In this context roundabouts around the world are often seen as a beneficial measure.  
55 According to Austroads (6) roundabout is the safest intersection design, mostly due to lower number  
56 of conflict points, and generally lower speed. Several studies demonstrated roundabout conversion  
57 benefits in terms of before-after crash frequency reductions. For example a study of 23 conversions in  
58 US found following reductions: 40% with all crashes, 80% with injury crashes, 90% with fatal crashes  
59 (7). Meta-analysis of 28 studies outside of US showed 30% to 50% reduction in the number of injury  
60 crashes; fatal crashes were reduced by 50% to 70% (8).

61 In recent decade the number of roundabouts have grown also in the Czech Republic, up to  
62 current number over 1,200. Czech roundabouts are typically unsignalized, located on urban roads,  
63 with 4 legs and single lane (9). Their typical diameter is 30 – 40 m, with lane width 6 – 7 m, average  
64 traffic volume 12,000 vpd. Some example photographs are presented in Figure 1.

65



66 **FIGURE 1 Examples of Czech roundabouts.**

67 However, although roundabout conversions are relatively common in the Czech Republic,  
 68 their safety impact has not been fully studied still. Previous Czech studies were not well designed and  
 69 based on small samples chosen in a convenient way. For example Pokorný (10) used cost-benefit  
 70 analysis with a limited sample of roundabout conversions. Another Czech study (11) assessed safety  
 71 of roundabouts using crash prediction models – however it comprised newly-built ones only (not  
 72 intersections being converted to roundabouts which are much more common).

73 In addition roundabouts have been sometimes seen as unpopular and vacant, including doubts  
 74 about their benefits, even from the Minister of Transport or Czech Police representatives (12). This  
 75 controversy and lack of solid knowledge inspired the authors to investigate following general  
 76 hypotheses related to Czech roundabouts:

- 77 1. Roundabouts are safer than traditional intersections.
- 78 2. Roundabout conversions are beneficial for safety.
- 79 3. Czech roundabout safety performance is comparable to other countries.

80 The first two hypotheses are inter-related and they consider two groups of intersections:  
 81 traditional intersections and roundabouts. The objective of the paper was to prove the hypotheses. The  
 82 text is structured in three chapters according to the hypotheses, followed by the final chapter with  
 83 results and discussion.

84

## 85 **2 GENERAL INTERSECTION COMPARISON**

86 The first hypothesis was “Roundabouts are safer than traditional intersections”. In order to quantify  
 87 general safety level of Czech intersections and compare it between traditional intersections and  
 88 roundabouts, two data sources have been used: crash information and road network information.

89 **Crash information**

90 In the Czech Republic traffic crashes have been routinely collected by Czech traffic police. There are  
 91 four severity levels: property-damage-only (PDO), slight injury, severe injury, fatal injury. Their  
 92 numbers, as well as their distribution according to several criteria, have been periodically published in  
 93 the annual reviews for several decades. However it has to be noted there were changes in crash  
 94 reporting thresholds, the last one taking place in 2009: since then PDO crashes have been reported  
 95 only when exceeding the value of CZK 100,000 (approx. \$ 4,500), while prior threshold was a half of  
 96 this value. This change created an incompatibility in time series of PDO crash numbers.

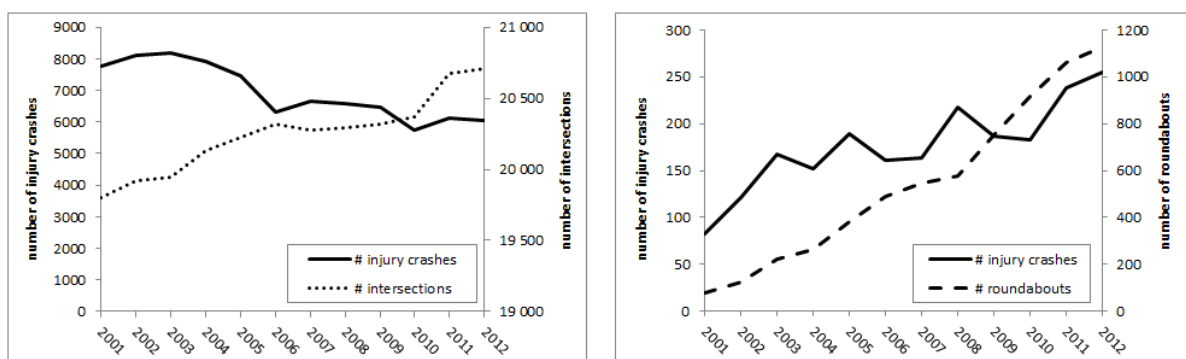
97 **Road network information**

98 Czech road network data have been administered by Czech Road and Motorway Directorate (RSD),  
 99 mainly for the purposes of asset management; in digital form (linked to GIS) it has been available  
 100 since 2001. While this is an important and rich information source, it has to be noted that RSD road  
 101 network does not cover local roads, thus neither intersections with these roads.

102 **Comparison**

103 Using above mentioned data sources, general safety performance of intersections may be visualized. In  
 104 order to avoid the mentioned incompatibility in PDO crash numbers, only injury crashes have been  
 105 considered. Graphs in Figure 2 show the numbers of injury crashes and intersections in period 2001 –  
 106 2012. Number of injury crashes was obtained from police reviews, number of intersections was  
 107 gathered from RSD databases.

108



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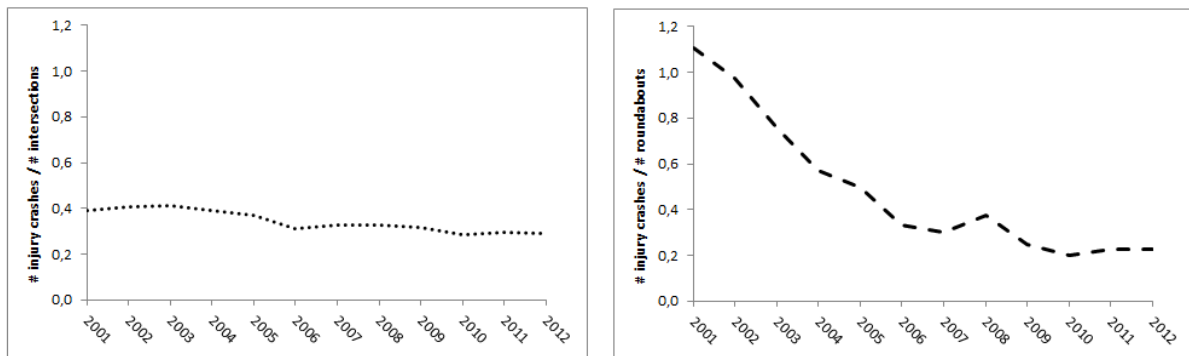
110 **FIGURE 2 Annual numbers of injury crashes at intersections and roundabouts (Czech**  
 111 **Republic, 2001 – 2012).**

112 For roundabouts indicators of both trends have been rising in the whole time period; on the  
 113 other hand number of injury crashes has been declining on traditional intersections. A relative  
 114 indicator of safety performance would be thus helpful. Ratio of number of injury crashes per  
 115 intersection was chosen for this purpose, defined as:

116 
$$ratio = \frac{\# \text{ injury crashes}}{\# \text{ intersections}} \quad (1)$$

117 Following graphs (Figure 3) show the resulting trends.

118



119

120 **FIGURE 3 Annual ratios of injury crashes per an intersection or roundabout (Czech Republic,**  
121 **2001 – 2012).**

122 Ratio has been relatively stable for traditional intersections; on the other hand it has been  
123 declining for roundabouts. However the absolute values are different, which may be caused by the fact  
124 that RSD databases (from which number of intersections was obtained) do not cover local road  
125 network. The relative coverage may be different for two compared intersection groups and the ratios  
126 may thus be incomparable, which prevents a firm conclusion.

127 Nevertheless in recent years (2009-2012) there were approx. 0.3 injury crashes per traditional  
128 intersection, while roundabouts yielded 0.2 injury crashes, indicating them as the safer intersection  
129 design. In addition the trends could indicate that safety at roundabouts has been gradually improving,  
130 while it has not changed at traditional intersections.

131

### 132 3 SAFETY EFFECTIVENESS OF ROUNDABOUT CONVERSIONS

133 The second hypothesis was “Roundabout conversions are beneficial for safety”. In order to quantify  
134 the safety effectiveness its crash modification factor have been calculated.

#### 135 Methodology

136 Crash modification factor (CMF) is a multiplicative factor used to compute the expected number of  
137 crashes after implementing a safety treatment at a specific site (roundabout conversion), through  
138 multiplication with expected crash frequency without treatment (13). A CMF value above 1.0  
139 indicates an expected increase in crashes, while a value below 1.0 indicates an expected reduction in  
140 crashes after the conversion.

141 In general several methodologies may be used in order to obtain CMF values. Before-after  
142 methodology, with empirical Bayes correction (in short “EB approach”) has been deemed the most  
143 suitable one. The method corrects for regression to the mean and other confounding factors (7, 14 –  
144 16).

145

146 In the EB approach, the change in safety for a site is given by (7, 17, 18):

147 
$$\pi - \lambda \quad (2)$$

148 where  $\pi$  is the expected number of crashes that would have occurred in the after period without  
149 conversion (reference group) and  $\lambda$  is the number of reported crashes in the after period. In estimating  
150  $\pi$ , the effects of confounding factors explicitly accounted for by estimating safety performance  
151 functions (SPF). SPF is used to estimate first the number of crashes that would be expected in each  
152 year of the before period at locations with traffic volumes similar to the one being analyzed. The sum  
153 of these annual SPF estimates ( $P$ ) is then combined with the count of crashes ( $x$ ) in the  $n$  years before  
154 the conversion in order to obtain an estimate of the expected number of crashes ( $m$ ) before conversion:

155 
$$m = w_1 \cdot x + w_2 \cdot P \quad (3)$$

156 where the weights  $w_1$  and  $w_2$  are estimated from the mean and variance of the SPF estimate as

157 
$$w_1 = \frac{P}{k+n \cdot P} \quad (4)$$

158 
$$w_2 = \frac{k}{k+n \cdot P} \quad (5)$$

159 where  $k$  is a constant for a given model (overdispersion parameter) and is estimated during the SPF  
160 calibration process with the use of a maximum likelihood procedure.

161 A factor is then applied to  $m$  to account for the length of the after period and differences in  
162 traffic volumes between the before and the after periods. This factor is the sum of the annual SPF  
163 predictions for the after period divided by  $P$ , the sum of these predictions for the before period. The  
164 result, after applying this factor, is an estimate of  $\pi$ . It is then summed over all sites in a group of  
165 roundabout conversions (to obtain  $\pi_{sum}$ ) and compared with the count of crashes during the after  
166 period in that group ( $\lambda_{sum}$ ). The variances  $\pi_{sum}$  and  $\lambda_{sum}$  are also computed and summed over all  
167 sites in the group of converted roundabouts.

168 The crash modification factor (or index of effectiveness)  $\theta$  and its standard deviation ( $SD$ ) is  
169 estimated as:

170 
$$\theta = \left( \frac{\lambda_{sum}}{\pi_{sum}} \right) / \left( 1 + \frac{var(\pi_{sum})}{\pi_{sum}^2} \right) \quad (6)$$

171 
$$SD(\theta) = \sqrt{var(\theta)} = \sqrt{\theta^2 \left( \frac{var(\lambda_{sum})}{\lambda_{sum}^2} + \frac{var(\pi_{sum})}{\pi_{sum}^2} \right) / \left( 1 + \frac{var(\pi_{sum})}{\pi_{sum}^2} \right)^2} \quad (7)$$

172 The percentage change in crashes is then computed as  $100 \cdot (1 - \theta)$ .

### 173 Data and calculation

174 As already mentioned, the most typical Czech roundabout layout is: urban roads, unsignalized, 4 legs,  
175 single lane (9). Therefore such roundabout conversions were chosen for the study as a treatment group.  
176 In order to locate the converted roundabouts, geographical information system was used, utilizing data  
177 from the entire Czech Republic. 202 cases were identified – however this sample had to be reduced  
178 only to cases where traffic volume and crash data were available (traffic volume from national traffic  
179 census, crash data from Czech Traffic Police) – this reduction resulted in 18 cases. Crash frequencies  
180 and traffic data (sum of entering vehicles) have been assigned to them.

181 **TABLE 1 Characteristics of 18 studied roundabout conversions (urban roads, unsignalized, 4**  
 182 **legs, single lane) with before (B) and after (A) data**

Location	Year opened	Sum of entering vehicles		Years of data		Total crashes		Injury crashes	
		B	A	B	A	B	A	B	A
Hrabačov	2009	11,729	11,417	9	3	17	1	14	1
Karviná	2005	17,632	21,039	7	7	12	7	11	6
Lanškroun	2003	9,182	13,657	5	9	3	11	2	11
Lázně Bohdaneč	2003	11,073	17,348	8	9	13	7	9	6
Letovice	2007	11,506	12,112	12	5	13	0	11	0
Moravská Třebová	2003	12,807	13,773	8	9	11	4	8	3
Náchod 1	2003	15,168	21,588	4	9	6	6	5	5
Náchod 2	2003	26,971	21,760	5	9	3	9	3	8
Orlová	2003	9,851	11,432	2	9	0	2	0	2
Rokycany	2004	11,753	16,341	9	8	10	2	6	2
Rožmitál pod Třemšínem	2003	4,957	5,821	8	9	1	1	0	1
Šenov	2004	8,337	9,555	9	8	19	3	14	1
Třeboň	2002	13,576	16,325	7	10	3	11	12	8
Valašské Meziříčí 1	2002	17,091	21,593	1	10	1	5	0	3
Valašské Meziříčí 2	2002	22,868	34,845	1	10	1	4	1	3
Vrchlabí	2005	10,245	10,340	10	7	23	7	18	4
Vsetín	2003	11,363	13,431	5	8	2	4	2	4
Zábřeh	2009	14,682	11,745	14	3	40	0	32	0

183

184 Intersections of the same design as the treatment group, but not converted to roundabouts,  
 185 have been used as a reference group. Again the same filters had to be applied (traffic volume and crash  
 186 data available) and 66 cases were identified. Crash frequencies and traffic volume (sum of entering  
 187 vehicles) were assigned to them. Data period of 18 years (1995 – 2012) was used.

188 **TABLE 2 Descriptive parameters of 66 intersections in the reference group**

Variable	Minimum	Maximum	Mean	Sum
Sum of entering vehicles	898	21,384	6,957	459,182
Injury crashes	0	22	7	484
Total crashes	0	40	10	686

189

190 A prediction model (safety performance function) was fitted to reference group data, using  
 191 crash frequency as a dependent variable and traffic volume (sum of entering vehicles) as an  
 192 explanatory variable. Considering negative binomial data distribution, generalized linear modelling  
 193 with logarithmic link function was used. Regression parameters estimates were significant at 95%  
 194 confidence level. The prediction model had following form:

$$195 \quad \text{crashes/year} = \alpha \cdot (\text{sum of entering vehicles})^\beta \quad (8)$$

196 The resulting expected (predicted) crash frequency estimates have been adjusted via empirical  
 197 Bayes method.

198



199 **TABLE 3 Parameters of reference group prediction models: regression constants  $\alpha$  and  $\beta$ ,**  
 200 **overdispersion parameter  $k$ , with their standard errors (S.E.)**

Crash severity	$\ln(\alpha)$ (S.E.)	$\beta$ (S.E.)	$k$ (S.E.)
Total crashes	-2.998 (1.050)	0.609 (0.120)	0.357 (0.080)
Injury crashes	-3.278 (1.112)	0.602 (0.127)	0.352 (0.088)

201

202 **Safety effectiveness**

203 Following the procedure described in the beginning of Section 3, safety effectiveness was calculated.  
 204 The results are reported for total crashes and injury crashes. The values are in form of crash  
 205 modification factor (CMF) and percents of crash frequency reduction – see Table 1. Mean values are  
 206 accompanied by standard deviations (S.D.) and confidence intervals, computed using 95% confidence  
 207 level (i.e. cumulative probability 1.96) as follows (13):

208 
$$95\% \text{ confidence interval} = \text{mean} \pm 1.96 \cdot (\text{standard deviation}) \quad (9)$$

209 **TABLE 4 Crash modification factors (mean and standard deviation) and corresponding crash**  
 210 **reductions, both with confidence intervals**

Crash severity	Crash modification factor		Crash reduction	
	Mean (S.D.)	Confidence interval	Mean	Confidence interval
Total crashes	0.48 (0.08)	0.33 – 0.63	52%	37% – 67%
Injury crashes	0.47 (0.08)	0.32 – 0.63	53%	37% – 68%

211

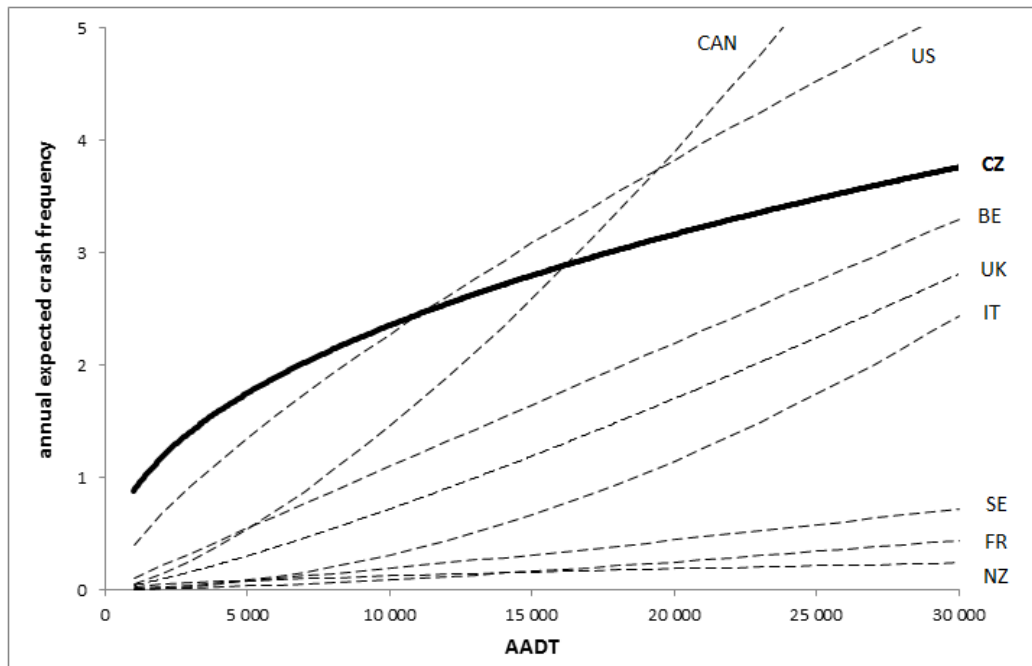
212 The results are positive and significant (the confidence interval do not include zero). Crash  
 213 reduction values are relatively consistent with previous studies – for example meta-analysis of non-  
 214 U.S. studies (8) reported crash reductions for 4-leg unsignalized roundabout conversions approx.  
 215 between 50% and 60%.

216

217 **4 INTERNATIONAL COMPARISON OF ROUNDABOUT SAFETY**

218 The third hypothesis stated that “Czech roundabout safety performance is comparable to other  
 219 countries”. Therefore illustrative international comparison was made, using simple safety performance  
 220 functions (SPF), which relate safety performance (usually annual crash frequency) to exposure (annual  
 221 average daily traffic volume, AADT) (19).

222 In line with previous analyses, only 4-leg single lane roundabouts, as a typical Czech  
 223 roundabout design type, were selected. In total 196 roundabouts were used for Czech SPF (for details  
 224 see 20). The Czech SPF was compared with several other models used in the world that were retrieved  
 225 from the literature (21 – 26). They included some European examples (Belgium, France, Italy,  
 226 Sweden, United Kingdom) as well as United States, Canada and New Zealand – see Figure 4. The  
 227 range of AADT values is limited between 10,000 and 30,000 vehicles per day.



228

229 **FIGURE 4 Comparison of Czech roundabout SPF with several international SPFs (BE –**  
 230 **Belgium, CAN – Canada, FR – France, IT – Italy, NZ – New Zealand, UK – United Kingdom,**  
 231 **US – United States, SE – Sweden).**

232 Considering the shape of curves, several conclusions may be made:

- 233 – Traditionally safe countries (Sweden, New Zealand) have the lowest expected crash frequencies.
- 234 – North American countries (United States and Canada) have similar shapes on the other side of the
- 235 range.
- 236 – Most European countries (Belgium, United Kingdom, Italy) have values between those two
- 237 thresholds.

238 Compared to North American SPFs Czech crash frequencies are higher at lower AADT and lower at  
 239 higher AADT (the threshold is approx. between 10,000 and 15,000 vehicles per day). However  
 240 compared to other European countries (and New Zealand) Czech SPF performs worse in the whole  
 241 range of AADT values.

242

## 243 5 RESULTS AND DISCUSSION

244 Three hypotheses were stated in the introduction: (1) Roundabouts are safer than traditional  
 245 intersections, (2) Roundabout conversions are beneficial for safety, and (3) Czech roundabout safety  
 246 performance is comparable to other countries. The paper provided the information and analyses in  
 247 order to test these hypotheses. The results are mixed – two hypotheses were accepted (positive results)  
 248 and one hypothesis was rejected (negative results):

- 249 – First hypothesis accepted: Compared to traditional intersections safety at roundabouts has been
- 250 gradually improving in recent years.
- 251 – Second hypothesis accepted: Roundabout conversions before-after study yielded positive crash
- 252 modification factors.

253 – Third hypothesis rejected: Czech roundabout expected crash frequencies are higher compared to  
254 other European countries.

255 However considering the international comparison of roundabout SPFs the reasons to the differences  
256 may be numerous; some of them are listed (for more see 26):

257 – *Various crash reporting practices.* Most countries report just injury crashes and data in graph  
258 reflect this fact. They should have therefore lower values compared to the Czech SPF, which  
259 utilized also property damage only crashes. However there are differences with crash reporting  
260 among specific countries as well: for example in Sweden and New Zealand approximately 40% of  
261 injury crashes are reported, while in United States it is 70% and even 100% in Italy.

262 – *Definition of intersection crashes.* There is no uniform criterion used for assigning a crash to an  
263 intersection. For example Belgian practice is to consider all crashes within an area of 100 m (the  
264 same holds for Czech data). However, in Canada 20 m limit is used, 30 m in Sweden and 50 m in  
265 New Zealand.

266 – *Design and traffic differences.* For example roundabouts in France have a long tradition; what is  
267 more, they were built there primarily for safety reasons. On the contrary, the United States and the  
268 United Kingdom use roundabouts mainly because of capacity. These underlying concepts dictate  
269 the roundabout design, e.g. the diameter. There are also international differences in the age of  
270 roundabouts and the data sets do not cover the same time periods or rural/urban areas. Also speed  
271 characteristics and climate conditions may be significantly different.

272 To sum up, safety level of roundabouts may be deemed sufficient in the Czech context: they are  
273 generally safer than traditional intersections, considering both new-builds and roundabout conversions.  
274 From this point of view there is no reason to limit the increasing trend of roundabout constructions.

275 Nevertheless at the same time Czech roundabout safety performance runs behind other several  
276 European countries. Although several methodological weaknesses in this comparison have been  
277 mentioned, this finding is consistent with general knowledge: Czech traffic is not sufficiently safe in  
278 European context and there is a room for its improvement. One of possible directions may be  
279 increasing safety situation on Czech roundabouts, as indicated in the paper.

280

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286

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