SAFETY EVALUATION OF CZECH ROUNDABOUTS

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ABSTRACT

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

1 INTRODUCTION

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

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

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

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

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

FIGURE 1 Examples of Czech roundabouts.

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

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

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

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

2 GENERAL INTERSECTION COMPARISON

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

Crash information

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

Road network information

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

Comparison

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

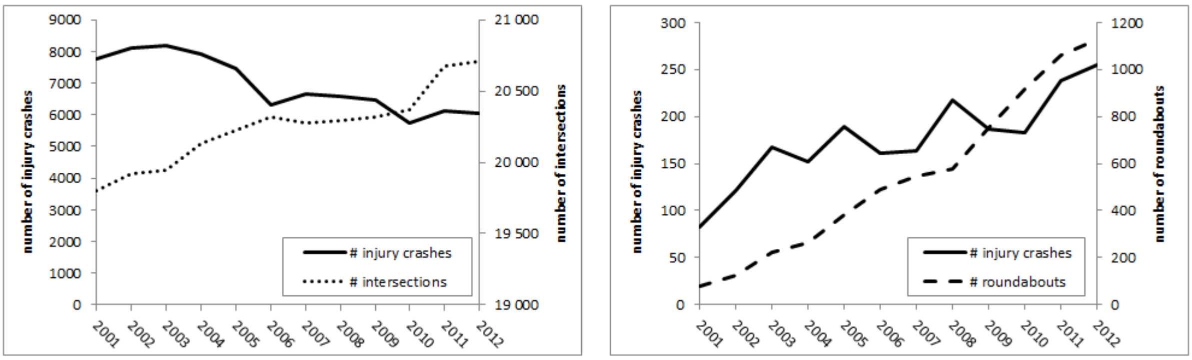

FIGURE 2 Annual numbers of injury crashes at intersections and roundabouts (Czech Republic, 2001 – 2012).

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

$$ratio = \frac{\#\,injury\ crashes}{\#\,intersections} \qquad (1)$$

Following graphs (Figure 3) show the resulting trends.

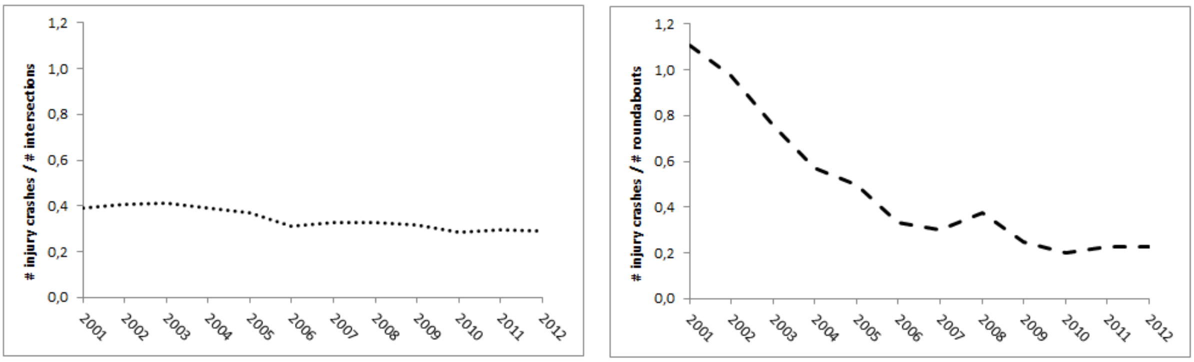

FIGURE 3 Annual ratios of injury crashes per an intersection or roundabout (Czech Republic, 2001 – 2012).

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

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

3 SAFETY EFFECTIVENESS OF ROUNDABOUT CONVERSIONS

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

Methodology

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

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

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

$$\pi - \lambda \qquad (2)$$

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

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

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

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

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

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

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

The crash modification factor (or index of effectiveness) θ and its standard deviation (SD) is estimated as:

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

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

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

Data and calculation

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

TABLE 1 Characteristics of 18 studied roundabout conversions (urban roads, unsignalized, 4 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

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

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

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

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

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

TABLE 3 Parameters of reference group prediction models: regression constants α and β, overdispersion parameter k, with their standard errors (S.E.)

Crash severity	$\ln(\alpha)$ (S.E.)	β (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)

Safety effectiveness

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

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

TABLE 4 Crash modification factors (mean and standard deviation) and corresponding crash 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%

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

4 INTERNATIONAL COMPARISON OF ROUNDABOUT SAFETY

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

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

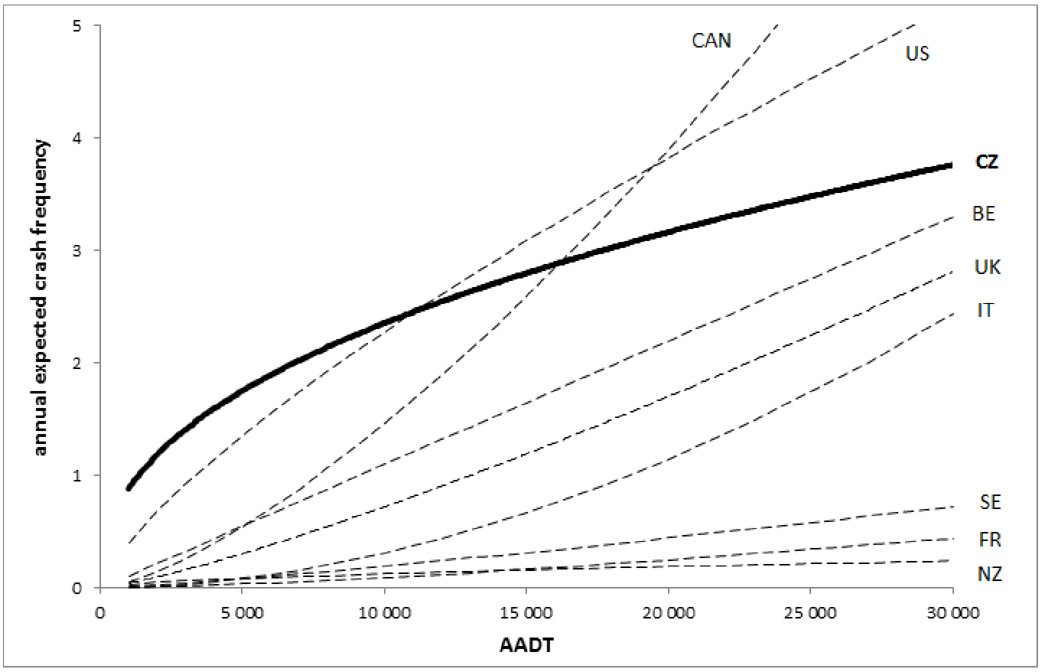

FIGURE 4 Comparison of Czech roundabout SPF with several international SPFs (BE – Belgium, CAN – Canada, FR – France, IT – Italy, NZ – New Zealand, UK – United Kingdom, US – United States, SE – Sweden).

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

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

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

5 RESULTS AND DISCUSSION

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

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

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

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

– *Various crash reporting practices.* Most countries report just injury crashes and data in graph reflect this fact. They should have therefore lower values compared to the Czech SPF, which utilized also property damage only crashes. However there are differences with crash reporting among specific countries as well: for example in Sweden and New Zealand approximately 40% of injury crashes are reported, while in United States it is 70% and even 100% in Italy.
– *Definition of intersection crashes*. There is no uniform criterion used for assigning a crash to an intersection. For example Belgian practice is to consider all crashes within an area of 100 m (the same holds for Czech data). However, in Canada 20 m limit is used, 30 m in Sweden and 50 m in New Zealand.
– *Design and traffic differences*. For example roundabouts in France have a long tradition; what is more, they were built there primarily for safety reasons. On the contrary, the United States and the United Kingdom use roundabouts mainly because of capacity. These underlying concepts dictate the roundabout design, e.g. the diameter. There are also international differences in the age of roundabouts and the data sets do not cover the same time periods or rural/urban areas. Also speed characteristics and climate conditions may be significantly different.

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

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

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