

Ivana MAHDALOVÁ¹, Tomáš SEIDLER², Denisa CIHLÁŘOVÁ³**INFLUENCE OF THE ROUNDABOUT GEOMETRY ON ITS SAFETY****VLIV GEOMETRIE OKRUŽNÍ KŘÍŽOVATKY NA JEJÍ BEZPEČNOST****Abstract**

The Department of Transport Constructions from the Faculty of Civil Engineering of the VŠB-Technical University of Ostrava is involved in a two-year research project for the Ministry of Transport. The name of the project is the influence of structural elements geometry on the safety and fluency of operation in roundabouts and possibility of rise crashes prediction. This paper presents certain interesting partial results of the research into the crash rate in roundabouts and possible reasons for traffic accidents rise resulting from geometrical layout.

Keywords:

Roundabout, traffic safety, traffic accident, relative crash rate, reasons for accidents.

Abstrakt

Katedra dopravního stavitelství Fakulty stavební VŠB-TU Ostrava aktuálně řeší dvouletý výzkumný projekt Ministerstva dopravy „Vliv geometrie stavebních prvků na bezpečnost a plynulost provozu na okružních křižovatkách a možnost predikce vzniku dopravních nehod“. V článku jsou prezentovány některé zajímavé dílčí výsledky výzkumu nehodovosti na okružních křižovatkách a možné příčiny vzniku dopravních nehod plynoucí ze stavebního uspořádání.

Klíčová slova

Okružní křižovatka, bezpečnost dopravy, dopravní nehoda, relativní nehodovost, příčiny nehod.

1 INTRODUCTION

Traffic Safety in roads is among actual topics and much attention is being paid to this. The idea which is being supported now is that the roads should be explanatory and forgiving. This means the driver should have a chance to understand easily and correctly the layout of the roads and intersections and consequences of a human failure, if any, should be as little as possible.

Roundabouts ranks among safety forms of road intersections. If the roundabout is well designed it forces the driver to drive the direction-curved driveway in a relatively low speed so that

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the driver could recognize the current situation in the crossing and react to it, as necessary. In a four-leg roundabout, there are considerably less conflict points than in a four-leg intersection - see Fig. 1. This means, in a roundabout there are objectively less points where vehicles could crash. It is, in particular, the single-lane roundabouts with single lane entries and exits which are the safest because crossing conflict points do not exist there - the crossing conflict points represent the major safety risk where a frontal crash of cars might occur with personal injuries or even fatalities. In multi-lane roundabout, vehicles move through crossing conflict points in the circulatory roadway when changing the lanes – it results in a much higher probability of cars and trucks crashing to each other.

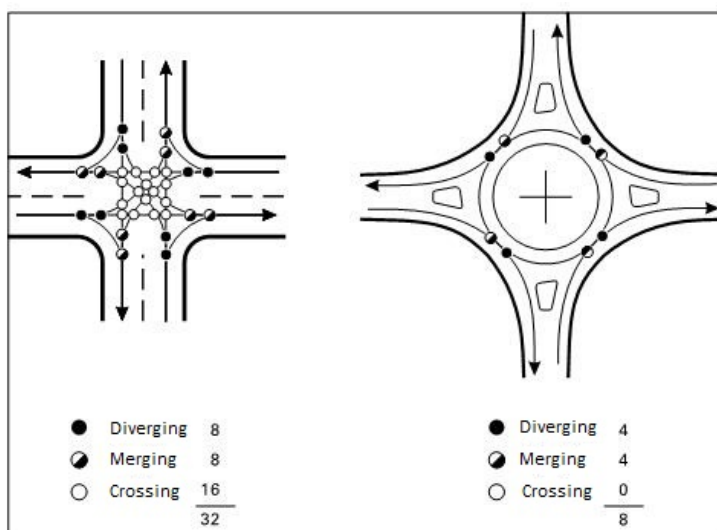


Fig. 1: Conflict points in a four-leg intersection and single-lane roundabout

The roundabout is not only more safety than a typical single-level intersection - it offers also other benefits. If the roundabout capacity is sufficient, it is almost not necessary for the vehicles to stop on approach. This minimises the likelihood of crashing a rear part of a front vehicle at the entry. The roundabout, unlike the light-controlled intersection, does not create a cyclical obstacle in traffic and is much safer than the light-controlled intersection. Furthermore, more roads and exits to houses can be connected directly to the roundabout. The number of connected entries/exits needs only a sufficient inscribed circle diameter of the roundabout. In the roundabouts, it is possible to eliminate an unsuitable crossing angle. The roundabout can be located even on a top of a concave vertical curve where a typical intersection can not be created because of poor visibility (for instance, the driver wants to turn left from the main road and should give way to opposite vehicles but those vehicles are hidden behind the horizon).

These benefits are making the roundabouts more and more popular abroad and in the Czech Republic. The existing intersections are being replaced with roundabouts, the objective being to increase the traffic safety. During construction of new roads and connection of commercial centres and industrial zones, the roundabouts are often the most frequent choice now.

But, not every roundabout fulfills expectations. If the geometry of elements is not chosen well and if traffic is high, the crash rate there may even increase. In 2009 and 2010, the Department of Transport Constructions from the Faculty of Civil Engineering of the VŠB-Technical University of Ostrava in cooperation with V-projekt Ltd has been involved in a research project for the Ministry of Transport. The name of the project is the influence of structural elements geometry on the safety and fluency of operation in roundabouts and possibility of rise crashes prediction. Within the research, data about roundabout crashes in the Czech Republic have been collected. The crashes took place in

2007 and 2008 and the sources of the data are records kept by the Czech Republic Police. For selected roundabouts, information was collected about traffic flow. Then, the relative crash rate was evaluated for the roundabouts and links to the geometrical layout were identified. The data cover 99 roundabouts from the whole of the Czech Republic with three up to five leg roundabouts - 86 hereof are single-lane roundabouts and 13 hereof are two-lane roundabouts. Types of the roundabouts are based on a relative occurrence of individual types of the roundabouts in the Czech Republic (the majority is four-leg roundabouts, less than 10% are multi-lane roundabouts).

2 COMPARING THE CRASH RATE IN SINGLE-LANE AND TWO-LANE ROUNDABOUTS

During the research, the relative crash rate in the roundabouts was evaluated and the conclusion is clear. The single-lane roundabouts, this means the roundabouts with single lane in the circulatory roadway and in the entry/exit are considerably safer than the multi-lane roundabouts where there are more (two, typically in the Czech Republic) lanes in the circulatory roadway or entry/exit. The two-lane roundabouts which were studied within the research were of the typical layout with two parallel lanes on the circulatory roadway. The modern layout of the so-called turbo roundabouts which should be safe could not have been evaluated in terms of statistics - according to available data, there is in the Czech Republic an only one turbo roundabout with no lights in Brno and a new turbo light-controlled roundabout in Havířov which was opened in September 2010 when it replaced the original standard two-lane roundabout.

Table 1: Relative crash rate in the roundabouts, 2007 - 2008

Number of lanes in the circulatory roadway	Average relative crash rate in the roundabout [number of accidents/million of vehicles]	Number of roundabouts evaluated in the category
1	0.50	86
2	2.19	13

Table 2. Approximate maximum capacity of the roundabouts according to [1]

Type of the intersection	Maximum hourly capacity [vehicles/hours]	Maximum daily capacity [vehicles/day]
Roundabout with a single lane in the circulatory roadway and a single lane in the entry ^{a)}	2,000 – 2,700	24,000 – 32,000
Roundabout with two lanes in the circulatory roadway and two lanes in the entry ^{a)}	2,500 – 3,500	30,000 – 40,000
^{a)} Depending on partial traffic flows.		

The comparison of the surveyed roundabouts indicates clearly that the relative crash rate, this means the number of accidents per million of vehicles entering the intersection, is on the average 4.4 higher in a two-lane roundabout than in a single-lane roundabout - see Table 1. There is a clear correlation between the higher crash rate and higher number of conflict points and existence of

crossing conflict points in the two-lane vs. single-lane roundabouts. But the capacity of the two-lane roundabouts is only 1.3 higher than that of the single-lane roundabouts - see Table 2. But the two-lane roundabouts are built just because of the higher capacity. This means that the slightly higher capacity of the two-lane roundabouts results in a considerably higher crash rate, if compared with the single-lane roundabouts.

3 SMALL = SAFE?

As mentioned in the beginning of the paper, the safety of a roundabout consists in the fact that the directional curvature of the driveway forces the driver to reduce the speed at the entry, giving thus more time to other drivers/pedestrians to react to the actual traffic situation. Collisions, if any, in low speed do not have any serious consequence and damage to property prevails, typically. It should be mentioned that only 3 fatalities occurred, according to Police's records, in the roundabouts in the Czech Republic in 2007 and 2008. Nevertheless, the total number of crashes is not negligible. For detailed data see Table 3.

Table 3: Total number of accidents and injuries in roundabouts in the Czech Republic - Police's records for 2007 and 2008

Number of lanes in the circulatory roadway	Year	Accidents per year	Injuries per year	Injuries-to-accidents rate	Type of injury		
					fatality	serious injury	slight injury
1	2007	1087	124	11,4 %	1	10	113
	2008	1063	179	16,8 %	1	27	151
≥ 2	2007	954	41	4,3 %	0	1	40
	2008	857	55	6,4 %	1	8	46

Note: The reason for few injuries occurred in the multi-lane roundabouts is that most accidents are side crashes when changing lanes with damage to property only and that there are minimum pedestrians who suffer, if involved in accidents, minimally slight injury always.

Non-experts as well as some experts often believe that a good choice for improved traffic safety is a roundabout with a small inscribed circle diameter. It is logical that with bigger diameters of the roundabouts the driving speed in the circulatory roadway increases considerably and the likelihood of serious collision increases as well. When designing a roundabout with a small inscribed diameter, it is necessary to use a sufficiently circulatory roadway wide so that it could be safe for big vehicles through path. Then, the central island has got a very small diameter which does not provide a sufficient directional deflection for cars and the cars move through the roundabout almost, or completely, directly. The drivers, when driving through the roundabouts, choose unconsciously (or even deliberately) the fastest path as flat as possible to reach the highest possible driving speed and to minimise the delay. During the survey, we evaluated vehicles paths which are easy to see in air photos of the roundabouts – they prove this fact clearly [2].

This means, these are not geometric values as the entry radius, inscribed circle diameter of the roundabout or the central island which are decisive for reduced speed in the roundabout - what is important is the mutual layout of those components that affect trajectory of the vehicles and the maximum driving speed there. In principle, it is necessary to evaluate geometry of vehicle paths as recommended, for instance, in [4].

This means that even a small inscribed circle diameter of the roundabout can be the reason for too high driving speeds and, consequently, more serious crashes. By the way, our research has not revealed any clear causal nexus between the inscribed circle diameter and occurrence of accidents. See the diagram in Fig. 2.

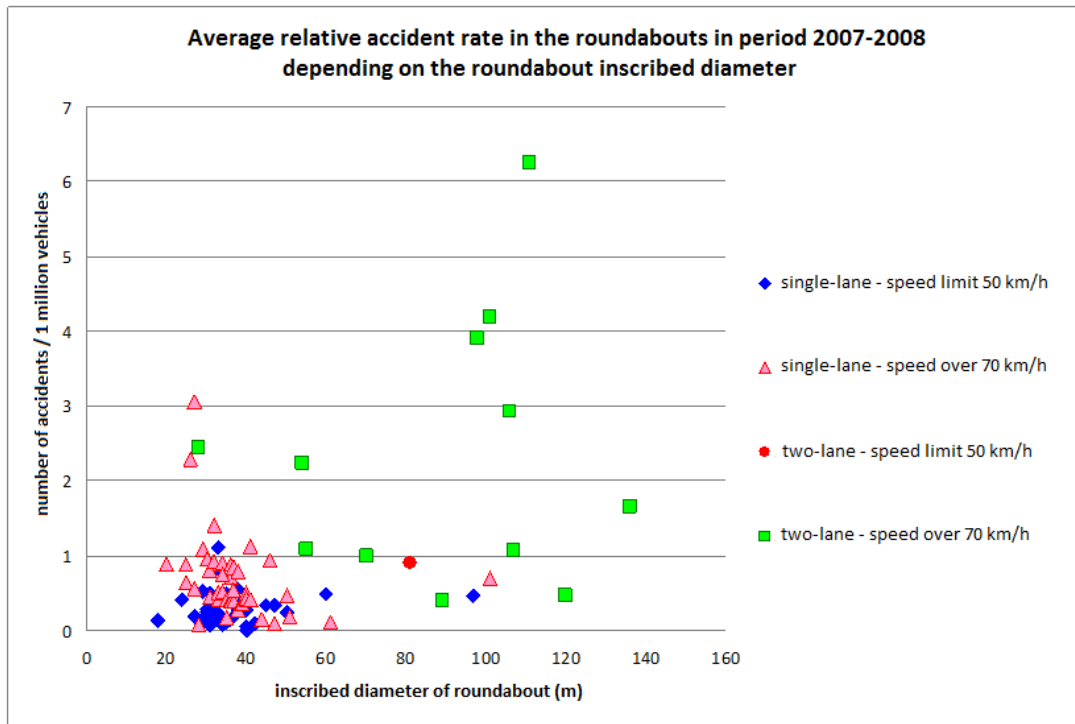


Fig. 2 Average relative crash rate in the roundabouts depending on the inscribed circle diameter and driving speed of the vehicles

4 RISK FACTORS FOR SAFETY IN ROUNDABOUTS

It follows from Fig. 2 that the safety at the roundabouts is clearly affected by other factors, not only by the size of the inscribed circle diameter. It depends on traffic flow in the roundabout, speed characteristics on approach roads to the roundabout and geometrical layout of the roundabout.

High traffic flow which exceeds considerably capacity of the roundabout represents a risk because queues appear at the entry to the roundabout and rear-end crashes are frequent – either into standing vehicles or during inching in a queue.

A important risk factor is location of the roundabout in a place where a higher speed limit is in force in approach roads. It is particularly the speed of 70 km/h and higher speeds on the approach road which affect considerably the accident rate. In that case, the drivers have to reduce much the speeds of their cars in a short road section so that they could safely enter the circulatory roadway - see Fig. 3.



Fig. 3 Reducing the speed at the approach road, R35, from Mohelnice, in front of the roundabout at suburbs of Olomouc (R35 continues in the first exit by a sharp cornering)

The situation becomes worse with the higher difference between the speed on approach road and the speed required for safety ride through the roundabout which decreases with the decreasing inscribed circle diameter of the roundabout. According to Article 5.2.1.5 in TP 135 [3] the designed speed is 30 km/h and 50 km/h for the roundabouts with the inscribed circle diameter below 50 m and above 50 m, respectively. In fact, the real speed necessary for the safe ride on the circulatory roadway in the roundabout is considerably lower - see Table 4.

Table 4: Approximate speed when driving on the circulatory roadway towards the third exit, depending on the inscribed circle diameter of the roundabout according to [4]

Inscribed circle diameter [m]	Approximate radius of the vehicle path on the circulatory roadway [m]	Approximate speed on the circulatory roadway [km/h]
30	11	21
35	13	23
40	16	25
45	19	26

If the difference between the approach speed and speed needed to drive through the roundabout is too big, following accidents can occur:

- The driver does not decrease the speed at all or decreases it too little, does not enter the roundabout properly and crashes the central island where he/she can collide with a fixed obstacle (such as a lamp pole, decorative components or decorative walls).

- The driver does not decrease the speed sufficiently, he still manages to enter the roundabout (the right-hand direction curve), but does not manage the next change in the direction (the left-hand curve) and leaves the circulatory roadway. Then he/she may crash into a fixed obstacle out of the roundabout (such as a lamp pole or handrails).
- The driver reduces the speed before the entry but not sufficiently. So he/she does not manage to pass around a small entry radius and rides through kerbs or destroys other components (marker posts, traffic signs or lamp poles) on the outer side of the entry. According to laws, these are accident because other party's property is damage. In spite of this, such accidents are not reported often.
- The driver reduces the speed sufficiently before entering the roundabout, but a driver driving the next car does not react in time and crashes the rear of the car in front of him/her.

The research has proved that the approach speed in the roundabout affects the accident rate. And this does not depend on whether the top permissible speed is limited by traffic signs. What is important is the layout of the road which makes it possible to drive in a higher speed. Within the assessment, the roundabout is classified for the speed category ≥ 70 km/h if at least one entrance makes it possible to enter the roundabout with the speed 70 km/h or higher. Table 5 shows results of the assessment.

Table 5. Average relative accident rate in 2007 and 2008 in surveyed roundabouts - dependence on speeds on the roads upstream the roundabout

Number of lanes in the circulatory roadway	Speed upstream the roundabout [km/h]	Average relative crash rate in the roundabout [number of accidents/million of vehicles]	Number of roundabouts for a specific category
1	≤ 50	0.34	45
	≥ 70	0.68	41
2	≤ 50	0.91	1
	≥ 70	2.49	12

Note: Two-lane roundabouts are very rare in locations where speed limit is 50 km/h.

5 INFLUENCE OF THE NUMBER OF LEGS ON THE ACCIDENT RATE

If it is assumed that the more conflict points exist, the higher the accident rate is in the roundabout, as is the case of the two-lane roundabouts, the accident rate should increase depending on the increasing number of the roundabout legs. This assumption has been proved – for results see Table 6. Because there are too few five-leg roundabouts among the roundabouts in the Czech Republic, they have not been included into the statistics assessment. Regarding the four-leg roundabouts, it is clear that the relative accident rate increases by about 30 to 50 per cent, if compared with the three-leg roundabouts in the same category.

Table 6. Average relative crash rate in 2007 and 2008 in surveyed roundabouts – dependence on the number of roundabout legs and approach speed

Number of lanes in the circulatory roadway	Speed upstream the roundabout [km/h]	Average relative crash rate in the roundabout [number of accidents/million of vehicles]			Number of roundabouts for a specific category		
		Number of roundabout legs			Number of roundabout legs		
		3	4	5	3	4	5
1	≤ 50	0.29	0.40	0.24	20	23	2
	≥ 70	0.54	0.70	0.85	6	33	2
2	≤ 50	--	0.91	--	--	1	--
	≥ 70	1.73	2.68	1.0	3	8	1

6 CONCLUSION

It follows from the research that the safety at the roundabouts is affected by the general geometry – not only by the inscribed circle diameter or entry/exit radii. The safety is considerably affected by the number of traffic lanes and roundabout legs because these factors influence the number of conflict points in the roundabout. It has been also proved that the higher approach speeds increase the number of accidents in roundabout.

ACKNOWLEDGEMENT

This paper was co-funded by the Ministry of Transport of the Czech Republic as a part of the research task No. CG911-008-910 “The influence of structural elements geometry on the safety and fluency of operation in roundabouts and possibility of rise crashes prediction”.

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