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SPEED REDUCTION EFFECTS OF URBAN ROUNDABOUTS

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Abstract. Road safety is one of the most serious problems in road traffic in many countries, including the Baltic countries. One of the alarming issues in road safety is the safety on urban crossings. As the number of intersections is still in a very bad and unsafe shape, there is a big need to reconstruct these intersections in a modern way. Roundabouts are coming more and more popular in many countries of the world, and often they are considered to be as one of the basic intersection types in urban areas. In Estonia, as in most European countries, roundabouts have steadily become more and more popular during the last years especially because of the foreign experience – showing the excellent accident records, traffic performance, and traffic calming properties. But still some doubts have been encountered in Estonia regarding potential capacity restrictions, traffic restrictions for big trucks and buses and sometimes with traffic safety treatments for bicyclists, pedestrians and the disabled. No overall statistics regarding the present number, growth rate, and design of roundabouts in Estonia are available. The goal of this paper was to find which factors could affect the drivers' speed choice at roundabouts. By the of obtained data we can follow up, that the main factor influencing the drivers' speed choice is an inscribed circle diameter of the roundabout.

Keywords: road safety, roundabout, speed.

1. Introduction

Road safety is one of the most serious problems in road traffic in many countries, including the Baltic countries (Ratkevičiūtė *et al.* 2007).

Most of the road deaths in Estonia involve vulnerable road users such as pedestrians and cyclists, which can mainly be attributable to drivers' behaviour aspects, such as choice of speed (Antov *et al.* 2007). High speed not only reduces the control of the vehicle, but also increases the fatality risk of a traffic accident (Garvill *et al.* 2003).

One of the alarming issues in road safety is the safety on urban crossings. Around 40% of all injury accidents reported to the police occur at intersections (Elvik, Vaa 2004). As the number of intersections is still in a very bad and unsafe shape, there is an urgent need to reconstruct these intersections in a modern way.

Roundabouts become more and more popular in many countries of the world, and often they are considered to be as one of the basic intersection types in urban areas.

In Estonia, as in most European countries, roundabouts have steadily become more and more popular during last years, especially because of the foreign experience – showing the excellent accident records, traffic performance, and traffic calming properties. But still some doubts have been encountered in Estonia regarding potential capacity restrictions, traffic restrictions for big trucks and buses and sometimes with traffic safety treatments for bicyclists, pedestrians and disabled road users. No overall statistics regarding the present number, growth rate, and design of roundabouts in Estonia are available.

The goal of this paper was to find which factors could affect the drivers' speed choice at roundabouts. By the obtained data we could follow up, that the main factor influencing the drivers' speed choice is an inscribed circle diameter of the roundabout.

Being widely accepted in Western Europe and Australia, roundabouts have been designed or constructed as replacements or alternatives to conventional intersections.

Many early applications of roundabouts eventually failed. In Estonia, many urban roundabouts, especially those constructed during the 1960s and 1970s, were rebuilt into signalized intersections as a result of poor capacity estimations and accident experiences.

Some researchers explained that the failures occurred because roundabouts were originally designed for merging and weaving manoeuvres at relatively high speeds, and thus required large diameters. Unfortunately, the merge distance was always too short for the speed and volume of traffic. The high-speed operations and the short distances were too difficult for drivers to safe manoeuvres (Taekratok 1998).

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Taekratok (1998) notes that in the mid-1960s, the United Kingdom adopted the "offside priority rule" for roundabouts, requiring the entering drivers to give way to those already on the roundabouts. This prevented traffic locking and allowed free-flow movement on the circulating roadway. It changed the drivers' task of merging and weaving at high speeds to the task of accepting a gap in traffic circulating at low speed.

With this new concept, safe and efficient operation of the roundabout now depends on effective measures to reduce vehicle speed. Slower traffic movement means that a large central island is no longer needed, and thus the use of much smaller roundabouts has become feasible. Consequently, there has been an increase in new and retrofitted roundabouts in many countries, including France, Norway, Finland, Sweden, Germany and other countries, as well as in the USA.

The Estonian Road Administration, local jurisdictions, and also their consultants are looking for alternative intersection solutions. Today roundabouts are one of the proposed solutions, even when there is no wide scale research on roundabout's capacity and safety effects in Estonia. That is why some doubts have been encountered towards the roundabouts in the country, especially regarding potential capacity restrictions, as well as traffic restrictions for trucks and buses; sometimes also with traffic safety treatments for bicyclists, pedestrians and disabled road users. When roundabouts were proposed, the first responses could most likely be against them because they thought it could cause some congestion problems. Many proposals were declined. As no overall statistics regarding the present number, safety effects, and even the design of roundabouts in Estonia are available and, unfortunately, the attempts to start the surveys regarding the safety effects of roundabouts to compare them with former intersection types (before- after studies) failed because of the lack or sometimes quality of accident statistics.

A major concern for roundabouts implementation is not the roundabout itself, but the former knowledge of old shape roundabouts and a bad reputation of these, which could be better defined as traffic circles. People still do not make a clear distinction between modern roundabouts and traffic circles.

The objective of this study is to evaluate some speed reduction effects of urban roundabouts as an intersection design solution. The study was divided into 2 stages, a literature review of roundabouts, and speed behavioural effects of roundabouts in Estonia.

The 1st stage collected available publications that address the issues associated with design, operation, safety, and public perception of roundabouts. The collected information was compiled and summarized for further evaluation and analysis. During the 2nd stage, a number of speed measurements were conducted on urban roundabouts with different inscribed circle diameter with the main idea of finding some potential effects of roundabout design parameters (inscribed circle diameter D) on actual driving speed on a roundabout.

2. International safety records of roundabouts

Safety improvement is the most distinct advantage of roundabouts. Traffic safety effects of roundabouts have also been the topic of several studies for the last decades (Daniels *et al*. 2008). International studies have unanimously demonstrated that the construction of roundabouts is an effective measure to improve traffic safety (De Brabander, Vereeck 2007).

Most areas that implement roundabouts experience an impressive impact on their accident record. A meta-analysis of 28 studies in 8 different countries revealed the best estimate of a reduction of injury accidents by 30–50% (Elvik 2003). A similar research, including 34 studies in 9 different countries (Great Britain, Denmark, Sweden, Norway, Australia, Netherlands, Switzerland, Germany, United States), conducted by Elvik and Vaa (2004) concluded that converting an intersection into a roundabout can reduce injury accidents by 10 to 40%, depending on the number of legs and the previous form of traffic control. Other studies, not included in the former one and using a proper design, delivered similar results (De Brabander *et al.* 2005; Persaud *et al.* 2001). Because of this remarkable reputation, during the latest 20 years, more and more intersections have been converted to roundabouts, both in Europe and in the USA, although the development in the USA has come later than in Europe (Hels, Orozova-Bekkevold 2007).

According Taekratok (1998) a higher safety at roundabouts is due to:

- a smaller number of conflict points in some circumstances;
- the avoidance of left-turn accidents, which is the cause of most fatal or serious accidents at cross intersections;
- the simplicity of decision-making at the entry point;
- the slow relative speeds of all vehicles in the conflict area;
- the protection of pedestrians on splitter islands which provide a refuge and permit crossing one direction of traffic at a time.

Elvik and Vaa (2004) have pointed out factors increasing the road safety at roundabouts:

- theoretically the number of conflict points between the traffic streams passing through an intersection is reduced from 32 to 20 at crossroads and 9 to 8 at T-junctions;
- road users entering roundabout are required to give way to road users already in the roundabout, no matter which road they are coming from, and thus are forced to observe traffic at roundabout more carefully;
- all traffic comes from one direction. Road users do not have to observe traffic from several directions at the same time in order to find a gap to enter the roundabout;
- roundabouts with offside priority eliminate left-turns in front of coming traffic;
- roundabouts are built so that road users cannot drive a straight path through the junction but must

drive round a traffic island located in the middle of the junction. This reduces speed.

Reduced speeds at roundabouts have been shown to be the primary cause of improved safety. Several studies have shown that there is a clear relation between the speed level and the number of accidents: even small changes in the speed level result in significant changes in the number of accidents and in the seriousness of accidents (Hydén, Várhelyi 2000). Hydén and Várhelyi (2000) conducted an experiment with small roundabout (middle-island diameter varying from 4 to 18 m) in a Swedish city. They tested long-term effects of the roundabouts. The results showed that the roundabouts reduced speed at junctions and on links between junctions. Speeding at these junctions was practically eliminated. Even four years after the implementation, mean speeds of approaches of those roundabouts was from the safety point of view in an acceptable level, significantly below the speeds in the earlier situation. Conflicts studies indicated an overall decrease in accident risk by 44%.

Nilsson (2004) has claimed a clear linear relationship between injury accidents and speeds based on before and after average speed and accident data. This results in a power-4 relation for fatalities, a power-3 relation for fatal and serious injuries, and a power-2 relation for all injury accidents (Nilsson 2004):

$$Y_i = \left(\frac{V_1}{V_0} \right)^{i+2} \times Y_0, \quad (1)$$

where i – the number of accidents (0 – injury accidents, l – severe and fatal accidents, 2 – fatal accidents); Y_i – number of accidents after changes in average speed; Y_0 – number of accidents before changes in average speed; V_1 – average speed after changes; V_0 – average speed before changes.

The correct approach speed is 30 km/h or less because at this speed practically all crashes between motor vehicles and pedestrians or cyclists end without fatal injury (Wegman, Aarts 2005). In order to guarantee this approach speed, however, the roundabout should meet the specific design requirements regarding a consecutive series of bends that motor vehicles have to follow when approaching and driving on a roundabout.

Roundabouts have an excellent reputation for improving traffic safety. It is also very important, that the roundabout installation can reduce fatal and serious accidents more (reduction of 70–90%) than slight injury accidents (Elvik, Vaa 2004). This also reduces overall accident costs.

In Germany, the conversion of conventional crossroads or T-junctions into roundabouts has resulted in a decrease of the overall accident costs by about 57%. The decrease of accidents with personal injuries is even more significant, particularly at rural crossroads.

Many dangerous intersections with several fatalities have been converted to accident-free intersections through the installation of a roundabout. Based on experience to date in Germany (Brilon, Vandehey 1998), it can be conservatively stated that compact roundabouts are likely to have at least 50% lower accident costs than conventional intersections. Outside of urban areas, converting cross-road intersections into roundabouts can reduce accident costs by more than 80%.

A secondary factor for improved safety is the reduced number of conflict points as compared to conventional intersections. The average speed in the inner circle of a compact roundabout is about 20 km/h. At uch a low speed, conflicts are normally avoided and the severity of accidents is greatly reduced. Because of the clear relationship between reduced speed and safety, it is important to ensure that the roundabout design will result in low travel speeds.

3. Data and method

The speed data was gathered on 11 urban roundabouts in the cities of Tallinn and Tartu, as well as in some smaller towns and settlements. Roundabouts chosen for the study had the inscribed circle diameter (D) between 15 m and 85 m.

The actual traffic was video recorded on all of these roundabouts and later the speed of driving on a straight ahead direction at a roundabout was measured by using the driving time inside the roundabout and combining this data with roundabout measured dimensions of the roundabout (driving distance inside the roundabout).

The roundabouts were classified into classes depending on their size, defined as inscribed D of the roundabouts. Here we find roundabouts starting with D less than 20 m up to over 70 m, when there were no roundabouts found with D between 50 m and 70 m. Thus the inscribed D classes were taken as follows: I less than 20 m (D < 20 m); II 20–30 m (D = 20–30 m); III 30–40 m (D = 30–40 m); IV 40–50 m (D = 40–50 m); V – over 70 m (D > 70 m).

The vehicles were also separated between cars, heavy goods vehicles (HGV) and buses.

4. Results

As a result of the survey, we carried out speed distributional analysis, based on calculated speeds of vehicles. Altogether the speed of 3268 vehicles was determined. The calculated speed distribution is presented in the Table and Fig. 1.

The speed distribution is smaller for smaller roundabouts (D < 20 m). Especially the roundabouts with D = 30–50 m have very large speed distribution and there is no

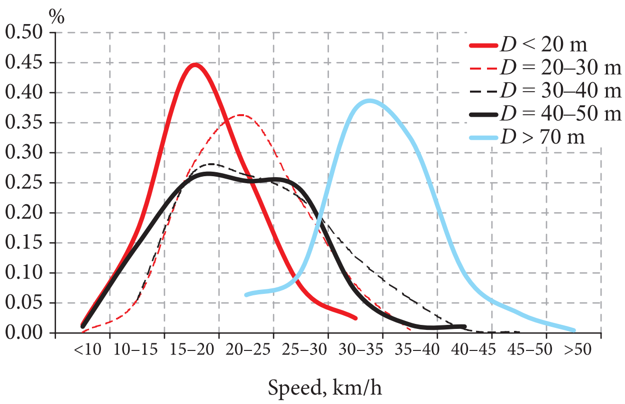

Fig. 1. Speed distribution on roundabouts

Table. Speed distribution on roundabouts

Speed gap, km/h	*D* < 20		*D* = 20–30		*D* = 30–40		*D* = 40–50		*D* > 70	
	No.	%	No.	%	No.	%	No.	%	No.	%
< 10	8	1	1	0			7	1		
10–15	97	17	54	6	34	6	96	15		
15–20	254	44	269	28	162	26	169	26		
20–25	154	27	351	36	161	26	166	25	29	6
25–30	44	8	213	22	137	22	156	24	47	10
30–35	14	2	78	8	78	13	46	7	171	37
35–40			5	1	35	6	9	1	149	33
40–45					4	1	7	1	45	10
45–50					1	0			15	3
> 50									2	0
Total	571	100	971	100	612	100	656	100	458	100

Note: No. is the number of roundabouts surveyed

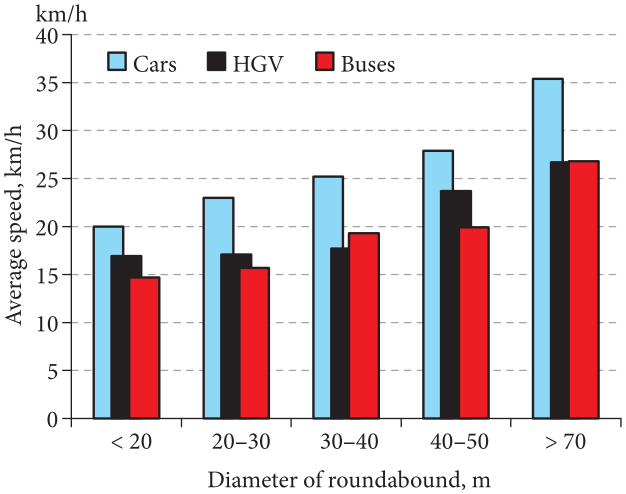

Fig. 2. Mean speed on roundabouts

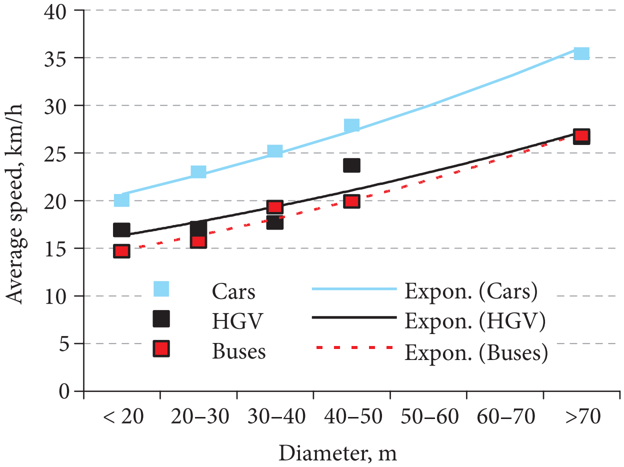

Fig. 3. Speed trends on urban roundabouts

clear difference between actual driving speeds of roundabouts with *D* = 30–40 and *D* = 40–50 m.

Also the mean speeds of cars, HGV and buses were calculated (Fig. 2). As presented, there is a clear tendency that mean speed is higher on bigger roundabouts for all vehicle types.

When comparing the speeds of different vehicle classes, we found that the roundabout size has rather similar influence on speed of all vehicle classes, but mean speeds of cars are higher than speeds of HGV and buses of all roundabout classes. But it is important that for roundabouts with a bigger size, especially the speed of cars, increases rapidly. When drawing out the general trends of average speeds for the roundabouts with different inscribed *D*, we can easily found some basic trends for all vehicle classes. There is also a tendency found, that big roundabouts do not make differences between the speeds of HGV and busses, when the speed of cars have increased rapidly (Fig. 3).

A speed reduction effect is clearly seen as an example of travel speed measurements on Tondi street in Tallinn (Estonia), where some small roundabouts were constructed few years ago. These roundabouts are relatively small (*D* = 25–35 m), and one of the main goals of roundabout introduction was especially the speed reduction in order to improve road safety, to avoid drivers to use high speeds, often up the speed limit (50 km/h). Speeds were registered with GPS installed observation car travelling in flow, as a result of 6 passes on this route. As it can be seen in Fig. 4, the roundabouts have a clear speed reduction effect, as the speed at the roundabout is up to half of the speed on links between intersections.

5. Conclusions

1. There is an expected reduction of speeds at roundabouts compared to other types of intersections.
2. The speed reduction effect is clearly dependent on roundabout design parameters, described here as an inscribed circle diameter *D*.
3. When the speed reduction effect and dependency on roundabout size is found, the safety effect of roundabouts could also be estimated.

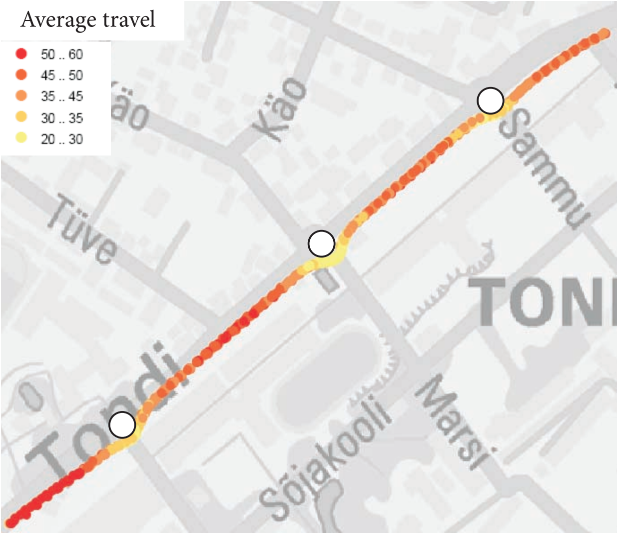

Fig. 4. Average travel speeds at Tondi street (Tallinn), passing 3 roundabouts

4. The present safety effects of roundabouts comparing with other types of intersections are based on international experiences and could be analyzed in the future based on local information, too.
5. There is no clear evidence in pedestrian and bicyclists safety effects at roundabouts and further investigation is recommended.
6. International studies can rate formulas that imply a relationship between geometry and accident rate at roundabouts. This is basically proved by the present survey, but some further investigations are still needed.

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