JSACE 4/9

Roundabouts as an Effective Tool of Traffic Management

Received 2014/06/17

Accepted after revision 2014/10/21

# Roundabouts as an Effective Tool of Traffic Management

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http://dx.doi.org/10.5755/j01.sace.9.4.7357

Driving speed is one of the most important factors in road safety and speed not only affects the severity of a crash, but is also related to the risk of being involved in a crash. Inappropriate speed is responsible for more than a third of all fatal accidents occurring on roads. In Poland every year majority of all traffic accidents occur in urban areas from which most is recorded at junctions and their vicinity. Hence it is of great importance to effectively manage speed and enforce speed limits on existing road network. Replacing already existing three- or four-arm junctions by roundabouts and construction new ones is considered to be a good solution for safety improvements and also are pointed to be within traffic calming features but their effectiveness is influencing by type, shape and geometry of the junction.

The aim of this paper is to analyse the effectiveness of chosen traffic calming measures in comparison with the effectiveness of roundabouts. Research area was located in city of Bialystok, Poland and included a group of commonly applied physical measures together with small and mini roundabouts. Measurements of instantaneous speed by utilizing GPS data logger and assessment of the extent impact of selected TCMs on drivers' manoeuvres were undertaken to develop the investigation.

**KEYWORDS:** traffic safety, speed, roundabouts, traffic calming measures, influencing zone.

## Introduction

Traffic management is related to planning, coordinating, controlling and organizing traffic to achieve efficiency and effectiveness of the existing road capacity. This includes techniques and strategies that generally are used to mitigate congestion, minimize delays, ensure smooth, fast but safe and economically reasonable conditions for vehicular movement from one place to another and are intended to improve traffic safety for all road users. Special attention in terms of traffic safety is given to speed management that emerges from the need to limit the negative effects of excessive and inappropriate speeds. Both excessive speed (driving above the speed limits) and inappropriate speed (driving too fast for the prevailing conditions, but within the limits) are within a definition of speeding and are very dangerous and undesirable. Speeding is being a causation factor in around one third of fatal accidents while speed is an aggravating factor in the severity of all accidents and more than two-thirds of these casualties occur at urban junctions. Furthermore it has also serious consequences on the environment and energy consumption. Hence arises the necessity of speed control and management.

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Journal of Sustainable Architecture and Civil Engineering
Vol. 4 / No. 9 / 2014
pp. 26-34
DOI 10.5755/j01.sace.9.4.7357

Sped management can be defined as a set of measures to limit the negative effects of excessive and inappropriate speeds and incorporate a wide range of measures. Special group that is distinguished within speed management creates traffic calming which is defined as the management of inappropriate vehicular speeds and volumes through educational, enforcement and engineering measures so that minimize their negative impacts on residents, pedestrians bicyclists and schools. Traffic calming measures (TCMs) are put in place on roads for the intention of slowing down or reducing motor-vehicle traffic to acceptable level as well as to improve safety for pedestrians and cyclists [O'Flaherty 2006, Guidelines 2006, Mini roundabouts 2012].

The main objective underlying traffic calming are to:

- reduce the higher speeds of vehicles in the traffic stream(s),
- create road conditions which encourage motorists to drive carefully and calmly,
- remove extraneous car and commercial vehicle traffic from the road being calmed,
- improve amenity and enhance the environment,
- reduce accident numbers and severity

however the key objective is that of reducing high vehicle speed.

Traffic calming schemes incorporate a wide range of measures although the effectiveness of this varies according to the measures employed. Specific measures may be grouped into four categories [Pennsylvania's 2008]:

- vertical deflection (road humps, bumps, lumps and tables, cushions, rumble strips, raised crosswalks and intersections),
- horizontal deflection (curb-extension, chicane, gateway, raised median island, traffic circle),
- physical obstruction (semi and diagonal diverter, right-in and righ-out island, raised median through intersection, street closure),
- signs and pavement markings.

Educational and enforcement cannot be underestimated in creation drivers' behaviour nevertheless engineering solutions related to changes of physical alignments of the street are most commonly used. Within spot traffic restraints from among a number of currently available devices vertical shifts placed on streets are the most effective in speed reduction [Ziolkowski and Saleh 2013] but their effectiveness is reduced to a very short section hence particular attention should be given to their location. Due to constraints limiting their usage those measures are mainly applied in residential streets in vicinity of places of a particular care due to the presence of children or where unprotected road users casualties are likely to occur.

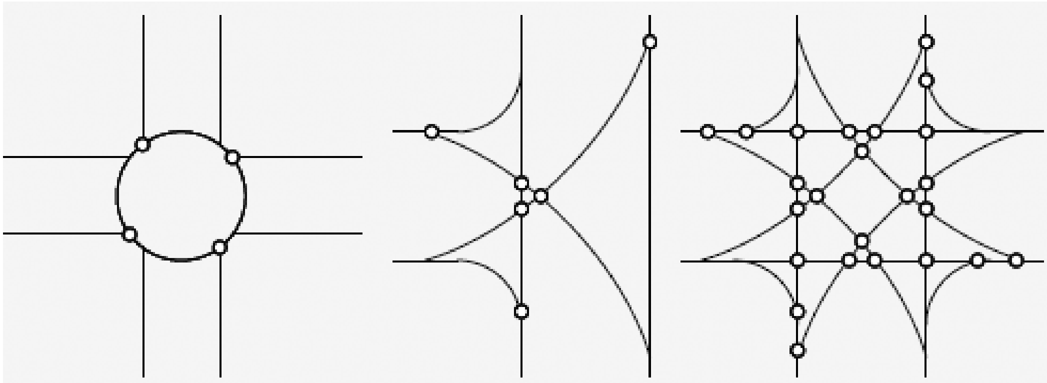
Another solution aiming at traffic calming although not very often met in undeveloped countries due to relatively high implementing costs are area-wide schemes. Through traffic is then removed from residential streets by implementing street closures or one-way systems or by establishing road streets hierarchy. Opposite to calmed area main roads do not involve the use of vertical shifts and are improved in order to carry a larger traffic volume without additional delays or more accidents. Those solutions reduce a number of traffic accidents more effectively in residential streets than on main roads.

## Roundabouts as a tool of traffic managem

Roundabout is type of circular intersection in which road traffic flows in one direction around a central island. According to [NCHRP Report 2000] there are three distinct types of circular intersections:

- rotaries – old-style circular intersections common to the United States prior to the 1960's, characterized by a large diameter that typically results in travel speeds within the circulatory roadway that exceed 50 km/h (30 mph),

Fig. 1
Conflict points on roundabout, T-junction and four-arm junction [Mini roundabouts 2012]



- neighborhood traffic circles – typically built at the intersections of local streets for reasons of traffic calming and/or esthetics. The intersection approaches may be uncontrolled or stop-controlled.
- roundabouts - circular intersections with specific design and traffic control features. These features include yield control of all entering traffic, channelized approaches, and appropriate geometric curvature to ensure that travel speeds on the circulatory roadway are typically less than 50 km/h,
- signalized traffic circles are circular intersections where traffic signals are used to control one or more entry–circulating point. This solution is not very common due to different operational characteristics from yield-controlled roundabouts, with queue storage within the circulatory roadway and progression of signals required.

According to Polish Standards [Wytyczne 2001] roundabout is defined as a circulatory intersection with a one-way circular roadway around a curb central island for circulating traffic with a small exception given to mini roundabouts which offer most of the benefits of regular roundabouts but are characterized by a small diameter and traversable island. Depending on the size of central island and inscribed circle diameter roundabouts are classified as: large, medium, small and mini.

Modern roundabouts require entering traffic to yield to traffic already in the circle and optimally observe various design rules to increase safety. They are used extensively worldwide to reduce accidents, traffic delays, fuel consumption, air pollution and construction costs, while increasing capacity and enhancing intersection beauty. They have been successfully used to control traffic speeds in residential neighborhoods and are accepted as one of the safest types of intersection design though study of safety in Bialystok [Ziolkowski 2013] have showed that roundabouts can be a place for a cumulative high number of collisions.

Considering roundabout as a mean of traffic calming they can be used in place of a traditional STOP intersection or traffic signal. Roundabouts require drivers to slow down to a speed that allows them to comfortably maneuver around the circle in a counterclockwise direction. The primary benefit of them is speed control and reduction in angle and turning collisions. From the safety point of view what matters is the number of collision points in a junction at which road users may possibly come into conflict with each other (Fig. 1). The fewer the potential conflict points, the safer the junction is (Fig. 1). Another aspect is the vehicle passing speed which while passing a roundabout is relatively low. Single-lane small and mini roundabouts are considered to be the safest in those terms.

Conventional roundabouts are appropriate for major collectors and arterials where they can reduce accidents and assist traffic flow. Mini roundabouts should only be used on distributors and minor collectors within residential areas where they increase the intersection capacity and promote safety [Mini roundabouts 2012].

## Sustainable traffic safety

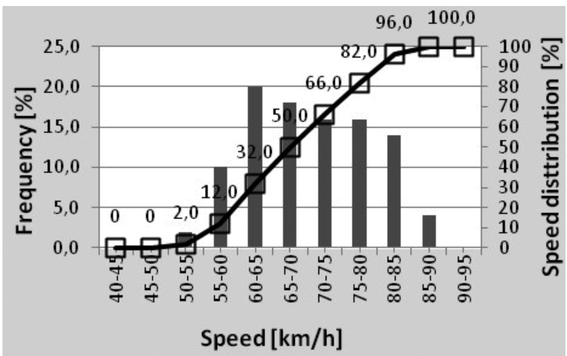
Sustainability in general means that everything that we need for our survival and well-being depends, either directly or indirectly, on our natural environment [Allen ..., 1980]. However when it comes to road infrastructure and traffic safety it is more appropriate to speak about sustainable development as “likely to achieve lasting satisfaction of human needs and improvement of the quality of human life” [Sustainable safety 2010] and sustainable safety - the approach to achieve and manage road safety. Sustainable safety is based on five principles: functionality of roads, homogeneity of speed, predictability of roads, forgiveness of road/street environment and state awareness by the road users. The principles originally were based on scientific research and theories from traffic engineering, biomechanics and psychology but after first few years experiences they have been expanded and presently also include infrastructure, vehicles, intelligent transport system, education and enforcement of laws and regulations. In a sustainably safe traffic system the main objective is preventing severe crashes and eliminating severe injuries when crashes occur as much as possible and in instances where prevention is not yet possible, the probability of severe injury should be reduced to almost zero. Roads and vehicles must be adapted to the human capabilities and the human has to be educated enough to be able to operate a vehicle on a road in a safe manner. In this terms highly dangerous in traffic remains large differences in speed and mass that the human being has to deal with so the fundamental is effective speed management.

## Problem of excessive speed in Bialystok

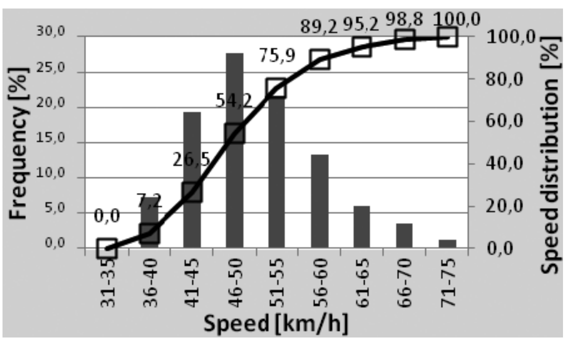
The problem of speeding drivers is widely common in Poland in both rural roads and urban areas. Polish experiences show that depending on the type of cross section the average percentage of drivers exceeding existing speed limits in rural roads ranges from 50 to over 70% while in cities this value ranges from 20 to 65%. The highest percentage of speeding drivers (up to 90%) was recorded on through roads in small towns [Gaca et al. 2004]. In Bialystok the number of speeding drivers is very troublesome and depends on road hierarchy, its function, geometry characteristics and posted speed limits. Previous studies [Ziolkowski 2012] have showed that the percentage of drivers exceeding speed limits vary from 32% (dual carriageway with speed limit of 70 km/h) to even 100% (single carriageway with a speed limit of 40km/h). The study has also revealed that in general non-intrusive administrative regulations as a tool of speed management are of low efficiency and traffic flow characterizes with a high heterogeneity (Fig. 2) which is very unfavourable in terms of traffic safety/drivers’ behaviour.

The need for more effective traffic management arises from low effectiveness of administrative1 tools and results in the common use of physical solutions of TCMs such as: speed humps, cushions and raised pedestrian crossings, intersections or median islands.

Hence the aim of this paper was to compare the efficiency between the use of roundabouts with the use of physical features in terms of their influence on drivers’ violence maneuvers and speed homogeneity.




a) posted speed 70 km/h




b) posted speed 50 km/h

Fig. 2

Speed distribution in relation to type of a road and posted speed limit a) dual carriageway, b) single carriageway

## Research area and methodology of data collection

Table 1
Geometry characteristics of selected roundabouts

| Type of roundabout | Geometry parameters | | |
|---|---|---|---|
| | Central island diameter [m] | Inscribed circle diameter [m] | Circulatory roadway [m] |
| Small (S1) | 21 | 34 | 4,25 |
| Small (S2) | 19,5 | 35 | 5,5 |
| Small (S3) | 24 | 40 | 4,8 |
| Mini (M_1) | 4,5 | 15 | 5,5 |
| Mini (M_2) | 10 | 21 | 5 |

Research area included mini and small roundabouts and chosen measures of traffic calming put in the streets located in Bialystok. Test drives were conducted in free flow driving conditions in order to avoid any disturbances arising from the presence of other road users. The summary characteristics of selected roundabouts are presented in Table 1 and the view of two examples of analysed roundabouts are presented in Fig. 3.

The data was collected by utilizing GPS data logger which allowed to monitor and record second-by-second in-field vehicle position and speed along tested sections. The vehicle's speed and position was collected by a test car in 1s interval during peak-off hours. The test vehicle was a passenger car and the employed drivers were suggested to drive according to their natural driving patterns. As a result a number of individual speed profiles for test sections have been achieved. Speed profiles with abnormal driving patterns were excluded from calculations of average speed profile.

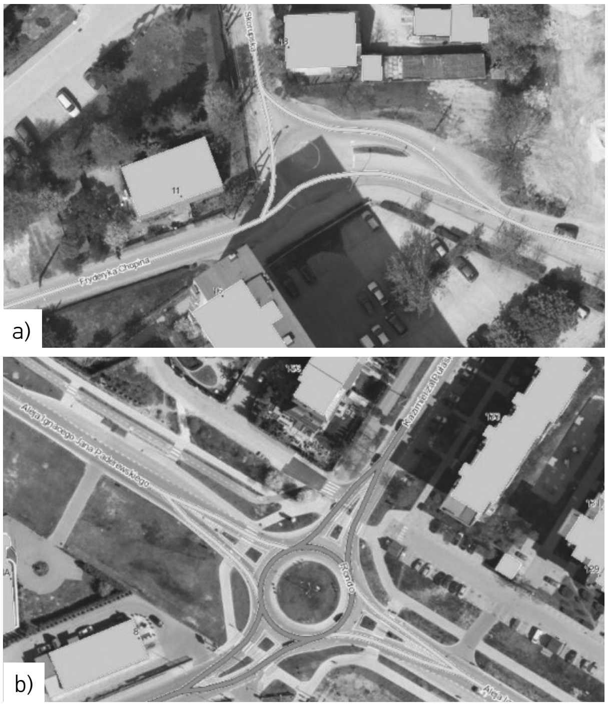


Fig. 3
Roundabouts subject to analysis a)mini roundabout M_1, b) small roundabout S_2

## Results and analyses

As a result a number of individual speed profiles were achieved (Fig. 4a) based on which average individual speed profiles were developed (Fig. 4b). Using these profiles drivers' behaviour in vicinity of roundabouts and selected TCMs were developed by assessing the influencing zones and speed differences between the beginning point set at the latest position where the vehicle's speed remained at a constant level in approach section and the end point set at a point where vehicle reached the lowest speed (Fig. 3b). End points were located before the yield line at the entrance in case of roundabouts and over a placement of a specific TCM. To evaluate traffic homogeneity in vicinity of traffic calming measures speed distribution charts were elaborated and are presented in Fig. 5 and 6.

A summary of the characteristics of key speed parameters produced in vicinity of TCMs are provided in table 2 and they present differentiated impact of analysed TCMs on average spot speed. The lowest average speed $V_m$=17.7 km/h is recorded for flat speed bump while the highest value

$V_r$=58.3 km/h is registered for raised median island. Hardly no differences can be seen between mean speed values recorded in vicinity of varied vertical deflections and the difference between the lowest and the highest values is only 4.1 km/h. The presence of raised median island has no distinct influence on average speed when compare to an average speed on a similar section without such a feature. The difference does not exceed a value of 3 km/h. The shape of a speed bump does not seem to substantially influence on drivers and the difference is only 2.3 km/h with almost the same standard deviation. Results provided in Table 2 show that the presence of speed cushion positively affects drivers who in its vicinity slow down but not as much as in vicinity of vertical shifts were mean speed value is lower by about 31%. On the other hand not all of the drivers passing through the cushion are slowing down equally which results in high speed variations and unfavourably high diversity ($V_{85}$-$V_{15}$=22.1 km/h). Presented data shows that high heterogeneity is also characteristic around raised median island ($V_{85}$-$V_{15}$=17.2 km/h). In vicinity of vertical shifts the speed variations is much lower and do not exceed 9 km/h. The most favourable situation in this terms is observed in case of raised junction where $V_{85}$-$V_{15}$=4.2 km/h.

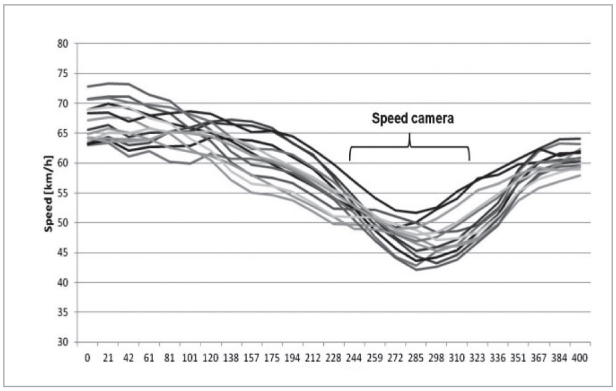
Figures 5 and 6 present charts of speed distributions in vicinity of chosen physical traffic calming measures.

Considering influencing zones in nearness of TCMs the largest extent is achieved for raised junction where average deceleration distance is 105 m and the shortest average braking distance (52 m) is for raised median island.

Table 2

Key speed parameters for analysed street sections

| Street | Mean speed $V_m$ [km/h] | Standard deviation | $V_{85}$- $V_{15}$ [km/h] | Type of calming measure |
|---|---|---|---|---|
| Tuwima | 19,4 | 1,53 | 4,2 | raised junction |
| Pułaskiego | 21,8 | 3,85 | 9 | raised pedestrian crossing |
| Wschodnia | 21,1 | 3,88 | 6,9 | rounded speed bumps |
| Kruczkow-skiego | 17,7 | 3,05 | 7,1 | flat speed bump |
| Kruczkow-skiego | 20,0 | 3,14 | 6,6 | rounded speed bump |
| Brzechwy | 29,1 | 9,8 | 22,1 | speed cushion |
| Pogodna | 58,3 | 8,96 | 17,2 | raised median island |

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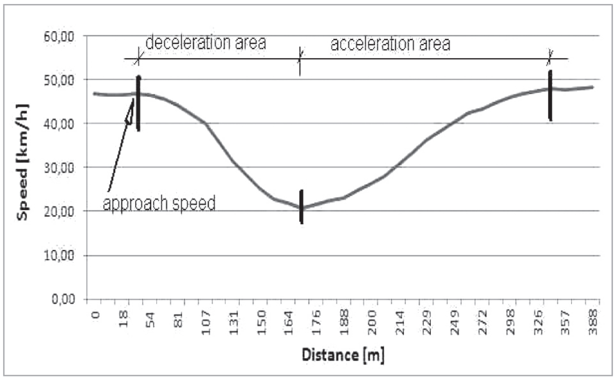


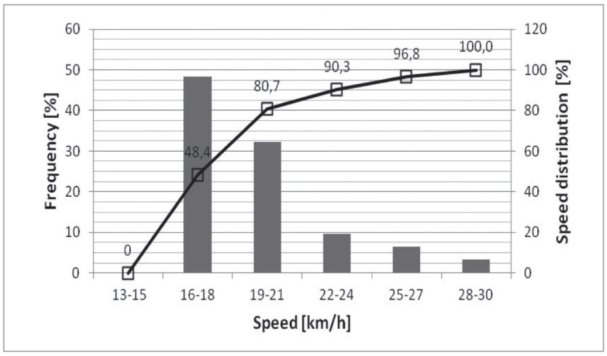

b)

Fig. 4

Individual speed profiles in vicinity of a selected TCM a) summary chart, b) average speed chart

Fig. 5

Distribution of instantaneous speed in vicinity of a) flat speed bump and b) rounded speed bump

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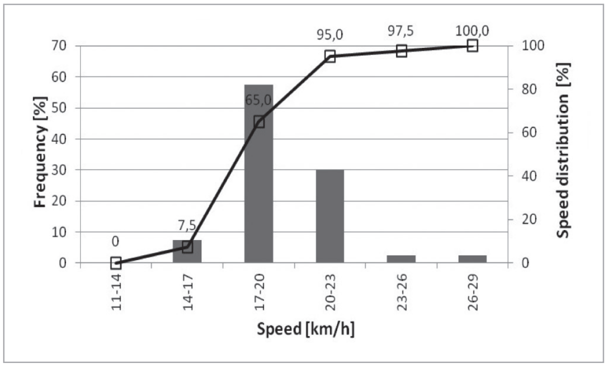
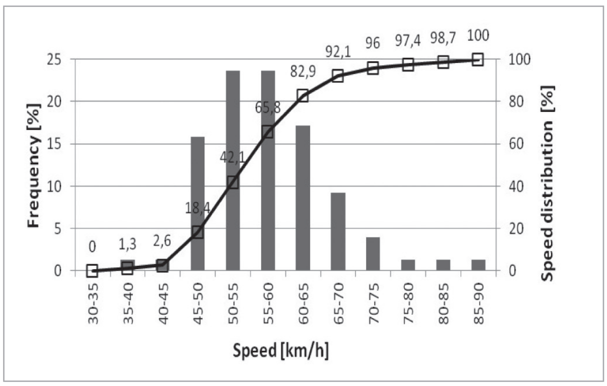


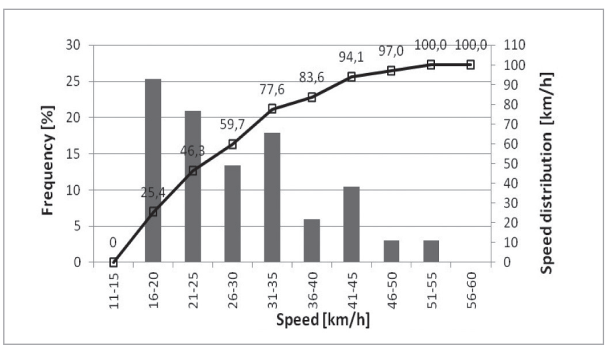

b)

Fig. 6

Distribution of instantaneous speed along a) raised median island and b) speed cushion




a)




b)

Analysing the effectiveness of roundabouts as a calming tool in terms of their affecting the average speed it emerges from Fig. 6 that the presence of these junctions essentially decrease vehicular speed and this influence depends on the type and size of roundabout. Average speed before roundabout influencing zone ($V_b$) is clearly related to the size of roundabout and decreases with the decrease in size of island diameter. On average, for small roundabouts $V_b$=43.34 km/h and is higher than $V_b$ recorded in vicinity of mini roundabouts ($V_b$=30.91 km/h). Similar relationship is evident in terms of speed on circulatory roadway ($V_r$). Average vehicular speed registered for small roundabout $V_r$=22.7 km/h is about 34% higher than average $V_r$ for mini roundabouts (14.9 km/h) recorded for mini roundabouts. The size of small roundabouts' central island diameters, opposite to mini roundabouts, do not seem to affect distinctly on speed on circulatory roadway. The difference between maximum and minimum value of $V_r$ within small roundabouts is 3.57 km/h while between mini roundabouts that difference is much higher and results in a value of 8.58 km/h.

In terms of speed reduction, as a result of roundabout presence, an average value ($V_b$-$V_r$) for small roundabouts is 20,67 km/h and is about 25% higher in comparison with speed reduction in vicinity of mini roundabouts. That difference can be explained by the geometry characteristics and horizontal alignment of adjacent streets which prevent drivers from speeding.

Considering the influence of type of roundabout on drivers braking decision small roundabouts have a greater impact on drivers in comparison with mini roundabouts. Drivers that approach the intersection start to slow down from an average distance of 115 m from small roundabouts and 88 m from mini roundabouts. However these values differ a lot depending on the type of roundabout and within a group of small roundabouts the achieved values of braking distance range from 59 m to 192 m. Within mini roundabouts these values range from 51 m to 117 m.

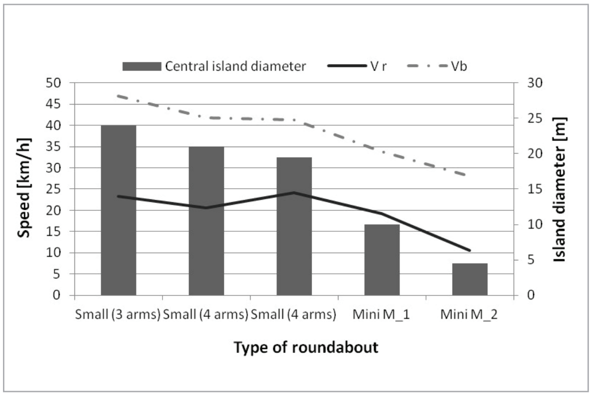



Fig. 7

Average speed in vicinity of roundabouts depending on the type of junction

## Conclusions

This study evaluated the impact of small and mini roundabouts on vehicle's speed in comparison with the impact of chosen traffic calming measures. Conducted measurements of instantaneous speed were employed to evaluate the effectiveness of roundabouts as a tool of traffic management in terms of speed reduction in comparison with typically installed traffic calming measures. Overall, it was found that the presence of roundabouts influence drivers' speed and behaviour depending on the type and size of a roundabout.

The presence of roundabouts positively decreases the average vehicle's speed. Mini roundabouts in this terms are more effective and average passing speed is lower by 34% as compared to the average speed in vicinity of small roundabouts. On the other hand it must be noticed that high heterogeneity of obtained results within mini roundabouts shows the need for further investigations in this scope on a wilder scale.

Comparing the influence of roundabouts on average passing speed with such an influence of chosen TCMs vertical deflections such as speed bumps and raides intersections prove to be most effective measures in speed spot reduction. However considering the driving style it must be emphasized that for drivers it is very important to drive smoothly without the necessity of violent speed reduction. In this light the use of small and mini roundabouts is reasonable.

The current study evaluated also high variety of results in terms of braking distance within small roundabouts. Some ambiguous results within analysed roundabouts reveal and highlight the need for in-depth research in terms of assessing the severity of maneuvers and range of the influence zone of specific TCMs and roundabouts. Based on that it will be possible to evaluate more firm and clear conclusions especially within groups of roundabouts regarding design suggestions for specific purposes.

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