Tamara Dzambas
PhD, Postdoctoral researcher
University of Zagreb, Faculty of Civil Engineering, Dpt. of Transportation – Zagreb
tamara.dzambas@grad.unizg.hr

Vesna Dragcevic
PhD, Full Professor
University of Zagreb, Faculty of Civil Engineering, Dpt. of Transportation – Zagreb
vesna.dragcevic@grad.unizg.hr

Dominik Benci
BCE
Benci-Prom d.o.o. – Zagreb
bencidominik@gmail.com

MODERN SUBURBAN ROUNDABOUTS IN CROATIA - FLOWER AND TURBO ROUNDABOUTS

Turboroundabouts are specially designed multilane roundabouts with spiral circulatory roadway and physically separated traffic lanes. This roundabout layout was developed in the late nineties of the last century with the aim of increasing the traffic safety and capacity at classic multi-lane roundabouts. However, the experience has shown that turbo roundabouts have certain deficiencies - due to its complex geometry and large outer diameters, the reconstruction of existing less safe multi-lane roundabouts into turbo roundabouts is financially very demanding. In that case, a construction of so called flower roundabout is much better solution. Namely, unlike in the case of turbo roundabouts, it is possible to adjust the existing multi-lane roundabouts into flower roundabouts without moving any of the outer road curbs. Within the scope of this study, geometric design and performances of these two modern roundabout types are analyzed. Their advantages and disadvantages in regard to performances of classic multi-lane roundabouts are discussed, examples from Croatian design practice are presented, and recommendations for their planning and designing are provided.

Keywords: comparison, flower roundabout, geometry, performances, suburban roundabouts, turbo roundabout

1. INTRODUCTION

Roundabouts have become increasingly used all over the world over the recent decades [20]. This intersection type has curved fastest path and lower number of potential conflict points in respect to classic signalized and non-signalized road intersections which results in greater traffic safety and higher capacity [18]. Furthermore, at roundabouts queue lengths are significantly shorter and speed profiles are notably smoother which leads to lower fuel consumption and lower emission of harmful gases [27]. However, it is necessary to stress that traffic safety in roundabouts significantly decreases with an increase of traffic lanes on roundabout approaches and circulatory roadway, and that the capacity of such roundabouts is often lower than predicted [10,

13]. The reasons for this are high driving speeds and large number of potential conflicts at multi-lane entrances, exits and circulatory roadway (Figure 1) [9].

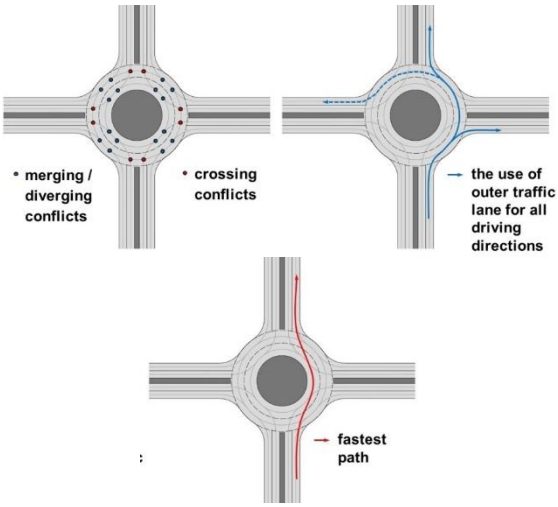

Figure 1. Disadvantages of multi-lane roundabouts

Following the above-mentioned findings, and the fact that several newer and safer types of multi-lane roundabouts (with significantly larger capacities and levels of traffic safety) were invented, in certain European countries (e.g. in Netherlands and Slovenia) the construction of classic multi-lane roundabouts is forbidden, and existing multi-lane roundabouts are being reconstructed [26].

2. SUBURBAN ROUNDABOUTS IN CROATIA

Roundabouts were not considered as a good traffic solution at the very beginning of their application in the Croatia. Namely, in the absence of domestic regulations and the lack of experience, foreign regulations (German, Austrian, and Swedish) were used and often misinterpreted, which resulted in a large number of improperly shaped roundabouts [1]. These first Croatian roundabouts had oversized circulatory lanes, and multi-lane approaches and circulatory roadways, which frequently led to previously described issues related with traffic safety and capacity.

However, an increasing number of roundabouts has been built in the Croatia in the last twenty years, and there is still a growing interest for them both by the investors and designers [1]. The reasons for this are numerous positive experiences of various Western European countries, including the neighboring Slovenia.

First Croatian guidelines for roundabout use and design [15] were published in year 2002. Main purpose of these guidelines was to achieve the commonality in the design and construction of all single- and multi-lane roundabouts at public roads in Croatia [21].

New Croatian guidelines for the design of roundabouts [16], published in year 2014, represent a significant upgrade of the first guidelines from 2002 in terms of the roundabout planning and designing i.e. the importance of swept path analysis for relevant design vehicle within the design process is emphasized [9]. Namely, the design of roundabouts is very specific due to the great variety of spatial and traffic factors, so it is not always possible to apply the optimal design elements and meet all the required criteria.

In the addition to above, according to these new guidelines [16] classic multi-lane roundabouts should be constructed only exceptionally i.e. special justification according to the criteria for checking the adequacy of the roundabout performance is required for the construction of such intersections. Moreover, separate guidelines for the design of newer and safer multi-lane roundabout, so called turbo roundabout, have been published in the same year [17].

Another alternative for classic multi-lane roundabouts are so called flower roundabouts. Unlike the turbo roundabout, these flower roundabouts are good traffic solution in the case of reconstruction of existing less safe multi-lane roundabouts. The reasons for this are as follows. When existing less safe multi-lane roundabout is converted into a flower roundabout all outer road curbs remain their positions (reconstruction costs are lower, and expropriation of surrounding land is not necessary). Contrarily, when existing multi-lane roundabout is converted into a turbo roundabout the position of all the kerbs of the circulatory roadway, splitter islands, and access roads needs to be changed, which is financially extremely demanding.

Flower roundabouts haven't been introduced to Croatian design practice, nor to design guidelines of this country. However, a number of classic single-lane roundabouts with bypass lanes for right turns, whose design elements and performances are quite similar to those of flower roundabouts, have. In the following text advantages and disadvantages of turbo and flower roundabouts in regard to performances of classic multi-lane roundabouts are discussed, examples from Croatia are presented, and recommendations for their planning and designing are provided.

2.1 TURBO ROUNDABOUTS

Turbo roundabout is a specially designed multi-lane roundabout with spiral circulatory roadway where the traffic flows at the entrance, circulatory roadway and exit are physically separated by raised mountable lane dividers [8]. Due to the physical separation of traffic lanes, driving speed is reduced, weaving conflicts are eliminated, and sideswipe collisions at roundabout entrances and exits are prevented (Figure 2) [9]. This roundabout type is recommended for use in the case of construction of new suburban multi-lane roundabouts due to its large outer diameters and multi-lane approaches.

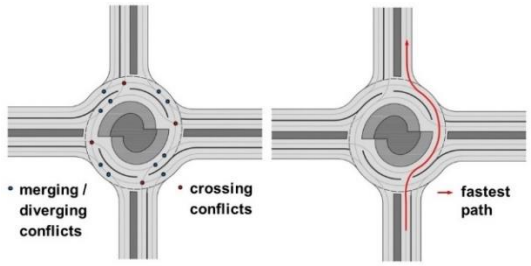

Figure 2. Conflicts and fastest path at turbo roundabout

According to Croatian guidelines [17], turbo roundabout planning and designing is an iterative procedure:

1. Selecting one of available turbo roundabout types (Egg, Basic turbo, Knee and Stretched-Knee - all these types should be used in the case of one dominant traffic flow) (Figure 3).
2. Defining a relevant design vehicle (truck with a semitrailer).
3. Creating one of given turbo block templates with inner radius from 10.45 m to 19.95 m (a turbo block is an auxiliary construction used in the design of spiral circulatory roadway) (Figure 4).
4. Designing the remaining turbo roundabout elements (circulatory lanes, central island, approaches, and lane dividers).
5. Conducting the required performance checks (design vehicle horizontal swept path analysis and fastest path vehicle speed analysis).

Iterativeness is reflected in the following: if analyses show that applied elements do not fulfil the swept path and/or speed requirements a redesign of roundabout elements is required.

It is necessary to stress that the design vehicle swept path should not be used not only as a performance check at the end of a design process, but also as a key parameter in geometric design of all turbo roundabout elements. Long term studies performed at the Department for Transportation of Faculty of Civil Engineering, University of Zagreb [8, 6, 7, 3, 22, 23] have shown that this design approach ensures the usage of optimal intersection element dimensions and an unhindered path for the design vehicle through the intersection.

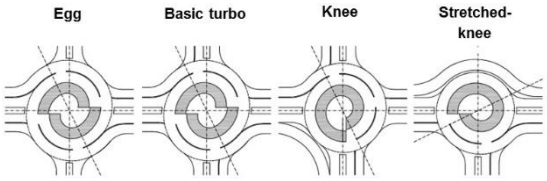

Figure 3. Turbo roundabout types given in Croatian guidelines [17]

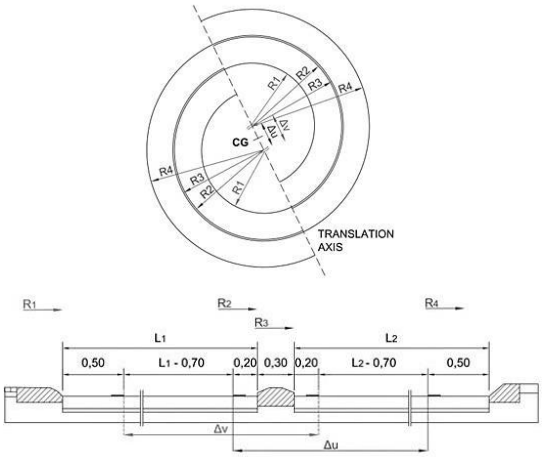

Figure 4. Turbo block design according to Croatian guidelines [17]

Studies involving turbo roundabouts show that this intersection type has a significantly lower number of traffic accidents in respect to classic multi-lane roundabouts. The use of this special multi-lane roundabout provides reductions of the number of total potential accidents between 40% and 50%, and reductions of the number of potential accidents with injuries between 20% and 30% [19]. In other words, traffic accidents at turbo roundabouts are extremely rare and usually result in material damage only [25]. Safety issues at this intersection type are mainly related to raised mountable lane dividers which represent a dangerous obstacle to motorcycles [4]. Moreover, these lane dividers hinder the maintenance and snow removal processes.

The capacity of turbo roundabouts is notably greater than the capacity of classic signalised and non-signalised road intersections [11]. However, if we compare them with classic multi-lane roundabouts, turbo roundabouts have greater capacity only in the case of one

dominant traffic flow i.e. in the case of equal traffic volumes on all approaches capacity of turbo roundabouts is lower or equal to the capacity of classic multi-lane roundabouts [12].

Recent studies that have addressed the impact of traffic flow conditions on the environment have shown that in terms of emissions of harmful gases the turbo roundabouts are less favourable traffic solution than classic multi-lane roundabouts [14]. Namely, traffic in turbo roundabouts produces less carbon monoxide (CO) and hydrocarbons (HC), but more carbon dioxide (CO_2) and nitrogen oxides (NOx) [28]. Furthermore, studies have shown that fuel consumption and emission of harmful gases is lower at turbo roundabouts with bypass lanes than at those without bypass lanes [2].

Egg turbo roundabout located near the city of Osijek in Croatia is shown in Figure 5. This is a good example of a properly shaped suburban turbo roundabout: its approaches are aligned radially under the angles of 90°; heavy vehicles and intercity buses are passing smoothly through the circular roadway; lane dividers are positioned adequately.

Figure 5. Turbo roundabout near the city of Osijek

2.2 FLOWER ROUNDABOUTS

Flower roundabout is specially shaped roundabout with right turn bypass lanes [24]. In this roundabout, right turners have their own separate traffic lanes, and there is no need for them to enter the circulatory roadway i.e. circulatory roadway is used only by the vehicles that are driving straight through the roundabout, the vehicles that are turning left, and the vehicles that are making U-turn. As shown in Figure 5, flower roundabout has only 8 conflict points at circulatory roadway and neither of them is a crossing or weaving (Figure 6).

This type of roundabout is recommended for use in the case of reconstruction of existing less safe multi-lane roundabouts. As mentioned above, unlike in the case of turbo roundabouts, when reconstructing the existing two-lane roundabout into a flower roundabout all the curbs of the circulatory carriageway, splitter islands, and access roads remain in the same positions (Figure 7) [26].

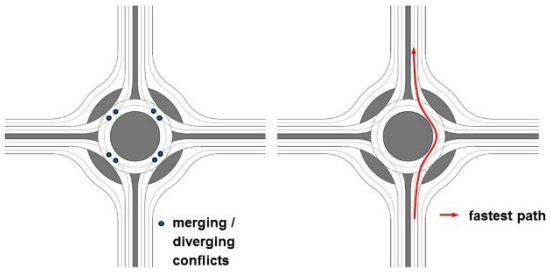

Figure 6. Conflicts and fastest path at flower roundabout

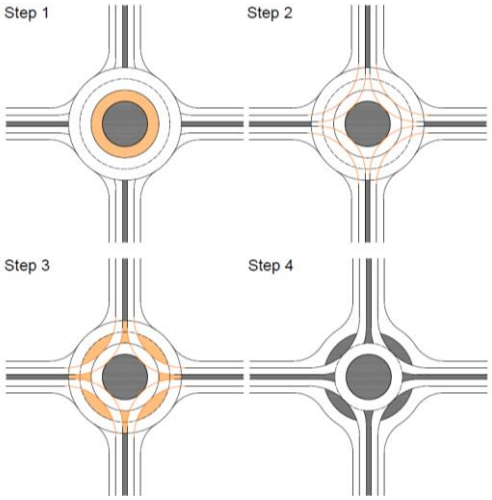

Figure 7. Reconstruction of classic two-lane roundabout to flower roundabout [26]

Flower roundabouts are rather simply a specific type of a classic single-lane roundabout with additional bypass lanes for right turns. These bypass lanes for right turns are separated from the outside edge of the circulatory roadway by a pseudo-elliptical traffic island, whose maximum width is equal to the circulatory lane width [5]. This roundabout solution can be implemented in four-lane as well as in two-lane roads. In the case of a two-lane road, an additional, sufficiently long entry/exit lane before the roundabout entry/exit should be planned [28].

In terms of traffic safety, the formation of these new entry/exit lanes at two-lane roads results in additional conflicts at roundabout approaches (8 new merging and emerging conflicts appear). However, the transfer of conflict points from the circulatory roadway to the road sections before and after the roundabout is considered as much safer traffic solution [25]. Generally, the bypass lanes for right turns can lead to speeding, and therefore, need to be used only at roundabouts in suburban areas, where number of non-motorized road users is reduced [24].

Recent studies have shown that flower roundabouts can be used whenever the circulating flow is below 1600 veh/h [5]. Up to that threshold they lead to higher capacities and lower delay than those in classic two-lane roundabouts. Contrarily, in the case of circulating flows higher than 1600 veh/h, the circulatory roadway tends to saturate and vehicles can't get onto it, and consequently entry flows reduce towards zero. It should be also noted that these roundabouts are advantageous compared to classic multi-lane roundabouts when a percentage of right turners reaches 60% of the total number of vehicles in roundabout [26].

Finally, there are no significant energetic and environmental benefits if existing classic multi-lane roundabout is replaced with flower roundabout at low traffic roads [5]. Moreover, if the traffic intensity is very high, two-lane roundabouts provide even better performances from this point of view. However, the use of flower roundabouts can lead to the potential reduction in fuel consumption and pollutant emissions only when the percentage of right-turns is higher or equal to 70% of the total traffic.

As mentioned before, flower roundabouts haven't been constructed in Croatia yet, but classic single-lane roundabouts with bypass lanes for right turns have. Such one classic single-lane roundabout with bypass lanes for right turns located near the city of Varaždin in Croatia is shown in Figure 8.

Figure 8. Classic single-lane roundabout with bypass lanes for right turns near the city of Varaždin [26]

3. CONCLUSIONS

A number of studies have shown that classic multi-lane roundabouts have poor traffic safety, and that the capacity of such roundabouts is often lower than predicted. The reasons for this are high driving speeds, and a large number of potential conflicts at roundabout multilane entrances, exits and circulatory roadway. In the past few years road designers are trying to solve these problems by introducing new roundabout layouts.

One such layout, which has been increasingly used in Croatian design practice in the last few years, is so called turbo roundabout. Because of its complex design, large outer diameters and multi-lane approaches, turbo roundabout is recommended for use in suburban areas. Furthermore, if existing multi-lane roundabout is converted into a turbo roundabout the position of all the kerbs of the circulatory roadway, splitter islands, and access roads needs to be changed, which is financially quite demanding. Turbo roundabouts have a significantly lower number of traffic accidents in respect to classic multi-lane roundabouts, but apparently their raised mountable lane dividers, which are important element of this road intersection, represent a dangerous obstacle for motorcycles. The capacity of turbo roundabouts is greater than the capacity of classic multi-lane roundabouts only in the case of one dominant traffic flow. Otherwise, their capacity is equal to or smaller than the capacity of classic multi-lane roundabouts. In terms of emissions of harmful gases this intersection is less favorable traffic solution compared to classic multi-lane roundabouts.

Flower roundabouts are much better alternative for existing less safe classic multi-lane roundabouts than turbo roundabouts - existing multi-lane roundabout can be replaced by a flower roundabout without movement of any of outer road curbs. In terms of traffic safety, fower roundabouts are much safer solution than classic multi-lane roundabouts. However, their bypass lanes for right turns might lead to speeding. Flower roundabouts should be used in the case of low traffic volumes, and in the case when a percentage of right turners reaches 60% of the total number of vehicles in roundabout. Contrarily, when the traffic intensity is high, and the percentage of right turners is lower than 60%, turbo roundabouts are notably better traffic solution. Finally, in terms of energetic and environmental benefits flower roundabouts are less favorable than classic two-lane roundabouts. Apparently, their use can lead to the potential reduction in fuel consumption and pollutant emissions only when the percentage of right-turns is higher or equal to 70% of the total traffic. In the light of above considerations, it would be advisable to provide the separate guidelines for the design of this particular roundabout type in further Croatian design guidelines.

REFERENCES

[1] Barišić, I., Jurković, S., Tollazzi T. (2007), „Enclosure to roundabout use improvement in the Republic of Croatia“, 4th Croatian Congress on Roads, Opatija Croatia, pp. 1-8.

[2] Bastos Silva, A., Mariano, P., Silva, J.P. (2015), „Performance assessment of turbo-roundabouts in corridors“, Transportation Research Procedia, Vol. 10, pp. 124-133.

[3] Bezina, Š., Stančerić, I., Ahac, S. (2016), „Swept Path Analysis on Roundabouts for Three-axle Buses - Review of the Croatian Design Guidelines“, 4th International Conference on Road and Rail Infrastructure, Zagreb Croatia, pp. 901-908.

[4] Brilon, W. (2015), „Roundabouts: A State of the Art in Germany“, National roundabout Conference, Vail USA, pp. 1-16.

[5] Corriere, F., Guerrieri, M., Ticali, D., Messineo, A. (2013), „Estimation of Air Pollutant Emissions in Flower Roundabouts and in Conventional Roundabouts“, Archives of Civil Engineering, , Vol. 59 No. 2, pp. 229-246.

[6] Džambas, T., Ahac, S., Dragčević, V. (2016), „Geometric design of turbo roundabouts according to Croatian and Dutch guidelines“, 4th International Conference on Road and Rail Infrastructure, Zagreb Croatia, pp. 893-900.

[7] Džambas, T., Ahac, S., Dragčević, V. (2016), „Design of turbo roundabouts based on the rules of vehicle movement geometry“, Journal of Transportation Engineering“, Vol. 142 No. 7, Pittsburgh USA, pp. 1-10.

[8] Džambas, T., Ahac, S., Dragčević, V. (2017), „Geometric design of turbo roundabouts“, Technical Gazette, Vol. 24 No. 1, pp. 309-318.

[9] Engelsman, J. C., Uken, M. (2007), „Turbo Roundabouts as an Alternative to Two Lane Roundabouts“, 26th Southern African Transport Conference, Pretoria South Africa, pp. 581-589.

[10] Fortuijn, L. G. H. (2009), „Turbo Roundabouts: Design Principles and Safety Performance“, Journal of the Transportation Research Board, No. 2096, pp. 16-24.

[11] Giuffré, O., Guerrieri, M., Grana, A. (2011), „Evaluating capacity and efficiency of turbo-roundabouts“, 88th Annual Meeting of TRB, Washington USA, pp. 1-15.

[12] Giuffrè, O., Granà, A., Marino, S. (2012), „Turbo-roundabouts vs. Roundabouts Performance Level“, Procedia - Soc. Behav. Sci., Vol. 53, pp. 590-600.

[13] Giuffrè, O., Granà, A., Marino, S. (2012), „Comparing Performances of Turbo roundabouts and Double lane Roundabouts“, Modern Applied Science, Vol. 6 No. 10, pp. 70-79.

[14] Guerrieri, M., Corriere, F., Lo Casto, B., Rizzo, G. (2015), „A model for evaluating the environmental and functional benefits of “innovative” roundabouts“, Transportation Research Part D: Transport and Environment, Vol. 39, pp. 1-16.

[15] „Guidelines for design and equipment at roundabouts“ (2002), Croatian Authority on Roads, Zagreb Croatia, 48 p.

[16] „Guidelines for the design of roundabouts at state roads“ (2014), Croatian Authority on Roads, Zagreb Croatia, 81 p.

[17] „Guidelines for the design of turbo roundabouts at state roads“ (2014), Croatian Authority on Roads, Zagreb Croatia, 42 p.

[18] Mahadalová, I., Seidler, T. Cihlářová, D. (2010), „Influence of the roundabout geometry on its safety“, De Gruyter, Vol. 10 No. 1, pp p. 1213-1962.

[19] Mauro R., Cattani, M. (2010), „Potential accident rate of turbo roundabouts“, 4th International Symposium on Highway Geometric Design, Valencia Spain, pp. 1-16.

[20] Montella, A., Turner, S., Chiaradonna, S., Aldridge, D. (2013), „International overview of roundabout design practices and insights for improvement of the Italian standard“, Canadian Journal of Civil Engineering, No. 40, pp. 1215-1226.

[21] Pilko, H., Barišić, I., Bošnjak, H. (2015), „Urban roundabouts“, 6th Croatian Congress on Roads, Opatija Croatia, pp. 1-9.

[22] Stančerić, I., Korlaet, Ž., Vesna, D. (2017), „New design procedure for four-leg channelized intersections“, Građevinar, Vol. 68 No. 4, pp. 257-266.

[23] Stančerić, I., Ahac, S., Bezina, Š., Vlaović, F. (2019), „Design limits for intersection angles between approach legs of suburban roundabouts“, Građevinar, Vol. 71 No. 5, pp. 389-399.

[24] Tollazzi, T., Renčelj, M., Turnšek, S. (2011), „New Type of Roundabout: Roundabout with Depressed” Lanes for Right Turning – Flower Roundabout“, Promet - Traffic and Transportation, Vol. 23 No.5, pp. 353-358.

[25] Tollazzi, T., Renčelj, M., Turnšek, S. (2011), „Slovenian Experiences With Alternative Types of Roundabouts - Turbo’ and Flower’ Roundabouts“, International Conference on Environmental Engineering, Vilnius Lithuania, pp. 1220-1226.

[26] Tollazzi, T. (2015), „Alternative types of roundabouts“, Springer, New York, USA.

[27] Varheyli, A. (2002), „The effects of small roundabout on emissions and fuel consumption: A case study“, Transportation Research Part D - Transport and Environement, Vol 7. No. 1, pp. 65-71.

[28] Vasconcelos, L., Silva, A., Seco, A., Fernandes, P., Coelho, M. (2014), „Turboroundabouts: Multicriterion Assessment of Intersection Capacity, Safety, and Emissions“, 93rd Annual Meeting of the Transportation Research Board, Washington USA, pp. 28-37.