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COMPARATIVE ANALYSE OF THE TWO NEW ALTERNATIVE TYPES OF ROUNDABOUTS – TURBO AND FLOWER ROUNDABOUT

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Abstract. Alternative types of roundabouts are usually more recent and have been implemented only in certain countries. Typically, they differ from "standard" roundabouts in one or more design elements, whilst the purposes of their implementations are also specific. The main reasons for their implementations are particular the disadvantages of "standard" one- or two-lane roundabouts in particular circumstances or changes of "actual circumstances" which in the past has led to roundabout implementations. Today, several different types of roundabouts are well-known ("mini", "double mini", "dumb – bell", "with transition central island", "with joint splitter islands", "traffic signal controlled", "assembled roundabouts" …), and it is possible to stipulate that they will be further developed in the future. This paper illustrates two relative new alternative types of roundabouts – "turbo" and "flower" roundabouts and their comparison from design, traffic safety and capacity point of view.

Keywords: roundabouts, two-lane roundabouts, alternative types of roundabouts, turbo roundabout, flower roundabout, comparative analyse.

1. Introduction

Firstly, the importance of traffic safety aspects – in general and especially at intersections – needs to be pointed out. Intersections are namely recognized as being among the most dangerous locations of a roadway network. Collisions and crashes at intersections have caused a huge cost to society in terms of death, injury, lost productivity and property damage. Those collisions and crashes at intersections differ from country to country, depending of intersections' types (Jasiūnienė *et al.* 2012).

Today, after many years of experience regarding roundabouts, there are still different ideas about the "ideal roundabout" with a little consensus on the crucial effects of rules on how to negotiate intersections. It needs to be stressed that the roundabout intersection has been "at the development phase" since 1902, and this development is still in progress. One of the results of this progress is the several types of roundabouts in worldwide usage today, called the "alternative types of roundabouts".

Some of the alternative types of roundabouts are already in frequent use all over the world (Brown 1995), some of them are more recent and have only been implemented within certain countries, and some of them are still at development phases. It is because of that we can call them "theoretical roundabouts".

Alternative types of roundabouts typically differ from "standard" one- or two-lane roundabouts in one or more design elements, as their purposes for implementation are also specific. The main reasons for their implementation are the particular disadvantages of "standard" roundabouts regarding actual specific circumstances. Usually, these disadvantages are highlighted by low-levels of traffic safety or capacities.

Lately, a growing number of foreign studies, as presented in scientific and professional literature, have pointed out the poor traffic safety characteristics of "standard" two-lane roundabouts, and the lower capacity that can be expected (Mauro, Branco 2010). In particular, speed at roundabouts also plays a significant role regarding safety: reduced speeds at roundabouts have been shown to be the primary cause of improved safety. In addition, these "standard" multi-lane roundabouts are also very expensive (Mauro, Cattani 2012).

It is for all these reasons that many countries are looking for a solution as to what to do with their existing "standard" multi-lane roundabouts in order to improve the level of traffic safety and capacity.

Different countries tackle this problem in different ways, which can be divided into four groups. Higher levels of traffic safety and capacities of "standard" multi-lane roundabouts are usually achieved by:

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– decreasing the number of driving lanes within the circulatory carriageway; not a good solution because the roundabout's capacity is decreased,

– decreasing the number of driving lanes at entries/exits; not a good solution because the roundabout's capacity is decreased,

– increasing the outer roundabout's diameter (whereby, the available length for weaving in the circulatory carriageway is increased); financially very demanding,

– decreasing the number of conflict points; a good compromise between the finances on the one hand and the increased capacity and traffic safety level on the other.

Recently, many countries have solved the problems of low traffic safety and capacities of existing "standard" multi-lane roundabouts by adopting the last of the above-mentioned methods – by decreasing the number of conflict points, which is one of the characteristics of some alternative types of roundabouts. One of them is the roundabout with a spiral course of circulatory carriageway (in short: the "turbo" roundabout), and another is the roundabout with "depressed" lanes for right-hand turning (in short: the "flower" roundabout).

2. Basic characteristics of turbo and flower roundabout

2.1. Turbo roundabout

The turbo roundabout is an innovative arrangement of the two-lane roundabout that has revolutionised roundabout design in the Netherlands. The turbo roundabout is a specific kind of spiralling roundabout that was developed by dr. L.G.H. Fortuijn (Engelsman, Uken 2007). A turbo roundabout is a special type of two-lane roundabout where some direction flows are separated or run on physically separated lanes (Fig. 1).

At the turbo roundabout the traffic flows run separately even before entry into the roundabout, they occupy separate lanes all the way throughout the roundabout, whereas traffic flows also run separately at the exit from the roundabout (Fig. 2). Physical separation of traffic lanes is interrupted only at the places of entry into the inner circulatory lane. Physical separation is achieved by specially-shaped elements - delineators, which hinder (but do not prevent) change of traffic lanes within the roundabout – weaving conflict points.

As weaving within the roundabout is no longer necessary, the delineator between the lanes can be slightly elevated. Such a mountable lane divider induces traffic to keep within its own lanes, and this helps to prevent sideswipe collisions that occur not only upon entering the roundabout but also when exiting it. As a result of lane dividers, drivers will need to choose the correct lane before they enter the turbo roundabout. Drivers need to be assisted by clear signposting and lane marking – a special form of arrow marking has been developed for turbo roundabouts, which makes for clearer lane selection (Fortuijn 2009).

The idea of the turbo roundabout was very rapidly transposed into several countries such as Slovenia, Germany, Denmark, Czech Republic, as also Hungary, Poland, Denmark and several other countries. According to the web page of Dirk de Baan, at present there are 320 turbo roundabouts all over the world, although it is questionable as what in some countries they understand under the terminus of a turbo roundabout.

The idea of turbo roundabouts was very rapidly taken up in Slovenia as well, over a few years. There were several reasons for this. One of the more important reasons was surely the fact that in the past, too small two-lane roundabouts were being constructed in Slovenia, which contradicted the statutory rule regarding the mandatory use of inner circulatory lane in cases, where the driver does not leave the roundabout at the next available exit: an average driver does not have the sufficient length to change the driving lane in the circulatory carriageway. For example, a similar problem concerning too small roundabouts being constructed was also reported for Lithuania (Žilionienė *et al.* 2010). The second of the more important reasons is that the inner circulatory traffic lane is not appreciated by young and senior drivers because they feel insecure when changing lanes on circulatory carriageways (Tollazzi *et al.* 2011a).

At the moment of writing this article, in Slovenia there are seven turbo roundabouts (Fig. 3), four under construction and design documentation for five turbo

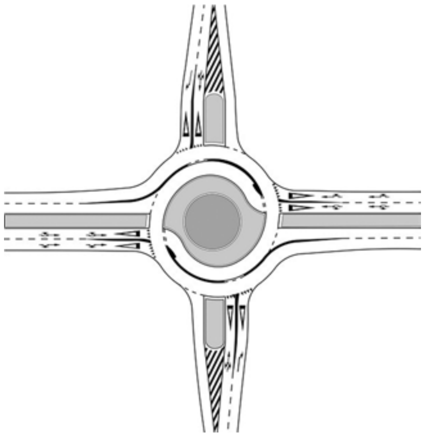

Fig. 1. Typical layout of a turbo roundabout (Fortuijn 2009)

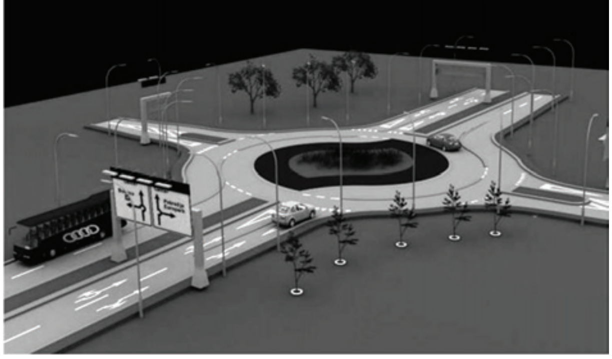

Fig. 2. Physical separation of traffic lanes in turbo roundabout (designed by Sašo Turnšek)

Fig. 3. Typical Slovenian turbo roundabouts (photo by Tomaž Tollazzi)

roundabouts is in process. All seven of the Slovenian turbo roundabouts are subjected to monitoring and analyses of their operations, as they are still "fresh" and it cannot yet be guaranteed that they will be as successful as in the Netherlands. Certain dimensions of the Dutch typical turbo roundabout, presented in *CROW 257: 2008 Turborotondes* (*Turboroundabouts*), have also been changed in order to suit Slovenian weather conditions.

It has been establish that turbo roundabouts in Slovenia have met the expectations concerning larger capacity and particularly the higher levels of traffic safety. Traffic accidents at Slovenian turbo roundabouts are now an exception and not a rule and these accidents normally result in only material damage. This was the reason for resigning from "standard" two-lane roundabouts (like in the Netherlands).

Notwithstanding the good general experience with the turbo roundabouts in Slovenia, the question was: What to do with the existing Slovenian, less safe, "standard" two-lane roundabouts? It would be an illusion to expect – mostly for financial reasons – that they could all be reconstructed into turbo roundabouts. The second solution was to try and combine the positive characteristics of different types of roundabouts whilst at the same time eliminating their negative characteristics. Thus, the question was: Is it possible to eliminate crossing and weaving conflict points within the existing "standard" two-lane roundabouts and thereby achieve higher levels of traffic safety without decreasing the roundabout's capacity?

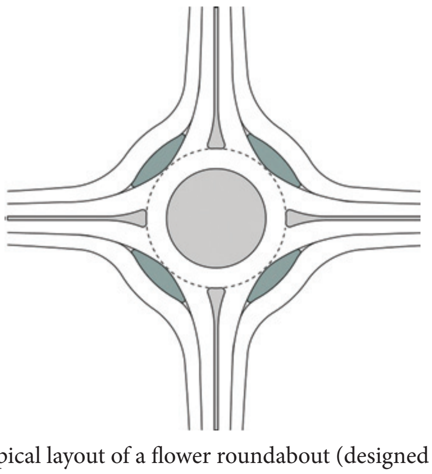

Fig. 4. Typical layout of a flower roundabout (designed by Sašo Turnšek)

The roundabout with "depressed" lanes for right-hand turners – the "flower roundabout" – is one of the possible solutions.

2.2. Flower roundabout

The roundabout with "depressed" lanes for right-hand turners – in short: the "flower roundabout" – was invented at the *Department for Roads and Traffic on Faculty of Civil Engineering, University of Maribor, Slovenia* (Tollazzi *et al.* 2011b), as a solution for achieving a higher level of traffic safety on existing, less safe two-lane roundabouts.

One of the basic characteristics of the flower roundabout is the same as for the turbo roundabout – physically separated traffic lanes within the circulatory carriageway. The second characteristic of flower roundabout is that all right-hand turners have their own separated lanes – bypasses, as are in frequent use all over the world (Fig. 4). This means that the inner circulatory carriageway is only used by vehicles that drive straight through the roundabout (180°), turn for three quarters of a circle (270°) or turn semicircle (360°). By physically separating the right-hand turning traffic flow, a one-lane roundabout is obtained, where (unlike in the turbo roundabout) there are no crossing conflict spots; however, (unlike at the "standard" two-lane roundabout) there are also no weaving conflict spots. They transfer from the circulatory carriageway (within the curve) to the road section before the roundabout (usually a straight line), which is a safer solution from the traffic safety point of view (Fig. 5).

Semicircle turning is possible from all directions from the inner circulatory lane (different to turbo roundabout). There are no crossing or weaving conflict spots within the circulatory carriageway (just 4 merging and 4 diverging).

This solution is possible for four-lane as well as for two-lane roads. In the case of the two-lane road, an additional sufficiently long traffic lane is implemented directly before the entry/exit.

Driving through a flower roundabout is like at "standard" two-lane roundabouts, and this roundabout type "forgives errors": if a driver mistakenly stays in left lane at the entrance, it still allows him to turn right at the next exit.

However, probably the best characteristic of the flower roundabout is that it is implemented within the existing "standard" two-lane roundabout.

3. Comparative analysis between the turbo and flower roundabouts

3.1. Design elements comparison

The best characteristic of turbo roundabout (different to flower) is that several different types exist (*CROW 257: 2008*). Selecting the type depends on the predominant direction of the main traffic flow. Namely, the predominant direction of the main traffic flow is the criterion for selecting the type of turbo roundabout.

The geometrical form of the turbo roundabout is slightly more complicated. It is formed by the so-called turbo block. This is a formation of all the necessary radii that must be rotated in a certain way, thereby obtaining traffic lanes or driving lines. The centre of a turbo block must be located in such a way that a radial connection of all entries is possible onto the turbo roundabout. The turbo block also contains (besides all radii) the so-called translator axle. A translator axle is an axle, which provides the movements of certain radii. The movements of radii depend on the widths of the circulatory traffic lane and the location of the verges (*CROW 257: 2008*).

Probably the best characteristic of the flower roundabout is that it is implemented within the existing "standard" two-lane roundabout. Therefore, bypasses for right-hand turners are not a novelty, as they are in frequent use all over the world. A novelty is that it is possible to adjust the existing standard (less-safe) two-lane roundabout into a (safer) flower roundabout without moving any of the outer roads' curbs, unlike in the case of the turbo roundabout (Fig. 6).

The reconstruction of an existing "standard" two-lane roundabout into a flower roundabout is easier and performed over four steps (Fig. 7):

Step 1: additional circulatory traffic lane is implemented towards the centre of the roundabout;

Step 2: construction lines of entries and exits are prolonged;

Step 3: splitter islands are prolonged for one circulatory lane towards the centre of the roundabout;

Step 4: redundant surfaces are rearranged into green areas.

3.2. Traffic safety comparison

A turbo roundabout is a most effective roundabout type than a "standard" two-lane roundabout from the traffic safety point of view. A typical turbo roundabout reduces the number of potential conflict points. Theoretically, 4 crossing points, 4 diverging spots and 6 merging conflict spots exist (Fig. 8).

This is theoretical but what does it mean in practice? It could be a problem on entering the turbo roundabout on

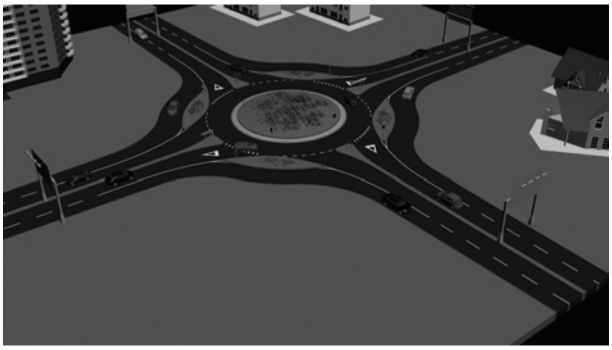

Fig. 5. Physical separation of the right-hand turning traffic flow at a flower roundabout (designed by Sašo Turnšek)

Fig. 6. Reconstruction of an existing two-lane roundabout into a turbo roundabout (designed by BPI Ltd. Maribor)

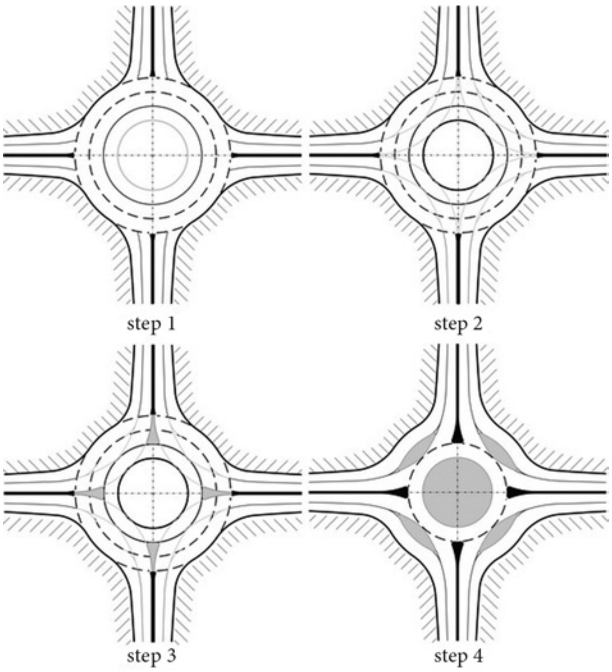

Fig. 7. Procedure for reconstructing of an existing two-lane roundabout into a flower roundabout (Tollazzi *et al.* 2011b)

the inner circulatory carriageway (Fig. 9). The fact is that in both cases, the driver during this traffic manoeuvre crosses a very strong traffic flow and, in the second case, enters the second, equally strong traffic flow, which causes a sense of insecurity and danger to the driver. Therefore, Slovenian experience is that these drivers enter the turbo roundabout very slowly or only when the vehicles within the roundabout are at a longer distance from them. Therefore, the crossing conflict spots within the turbo roundabouts in Slovenia have a significantly greater negative effect than expected, at least at the beginning of the introduction.

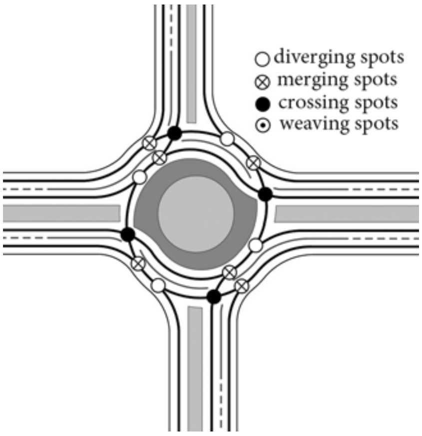

Fig. 8. Conflict spots within the standard turbo roundabout (4 crossing, 6 merging and 4 diverging) (Tollazzi *et al.* 2011b)

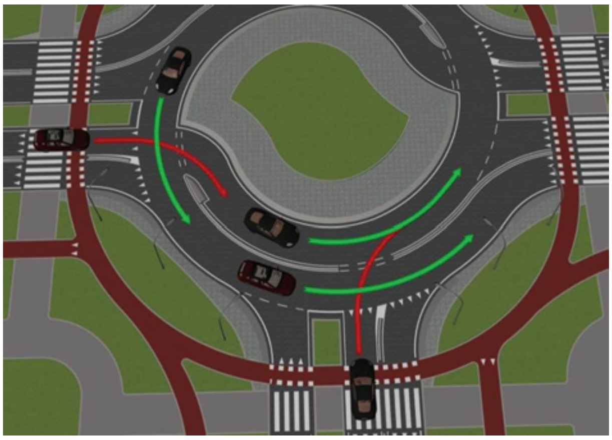

Fig. 9. Crossing conflict spots at the entry onto the inner circulatory carriageway from the inner lane at the entry (designed by Sašo Turnšek)

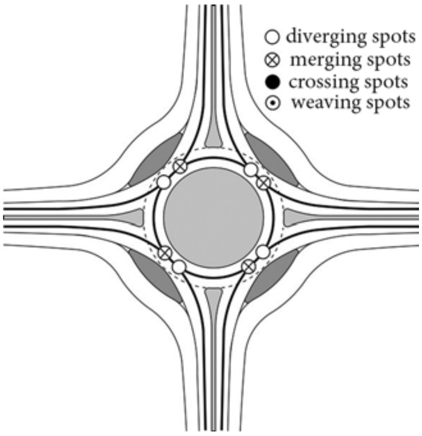

Fig. 10. Conflict spots within the flower roundabout (designed by Sašo Turnšek)

Within a flower roundabout, the situation is slightly better: by physically separating the right-hand turning traffic flow a one-lane roundabout is obtained, with no crossing conflict spots (unlike in the case of the turbo roundabout), and also no weaving conflict spots (unlike in the case of the standard two-lane roundabout). Any possible weaving conflict spots when transferring from the circulatory carriageway (along the curve) onto the road section (usually as a straight line) are in front of a roundabout.

In general, on flower roundabout all the vehicles are not "pushed" onto the roundabout (the roundabout is less occupied by traffic, reduced possibility of conflicts as a consequence), all vehicles turning right have their own, separate lanes, therefore the roundabout is one-lane (elimination of the conflict spots of crossing and weaving), and there are just 4 merging and 4 diverging conflict spots (Fig. 10).

3.3. Capacity comparison

Practical evaluation data is presently unavailable for turbo roundabouts because only in the Netherlands have a number of turbo roundabouts been realised and very few of those are operating on or near capacity.

Thus, there are different ways of determining the capacity of a turbo roundabout.

The Dutch guidelines for turbo roundabouts (*CROW 257: 2008*) do not contain equations for calculating the capacity of the turbo roundabout. However, they have a so-called quick-scan model, developed by the Province of South Holland in the Netherlands, for comparing the capacities of different types of roundabouts. This quick-scan model shows that the capacity of a turbo roundabout is about 25% to 35% higher than the capacity of a two-lane roundabout, depending on the balance of the traffic volumes on the approaches. These results are also dependent on the designs of the roundabouts and on the driver behaviour factors used in the quick-scan model. It is for that reason that the results should mainly be interpreted as a comparison between the turbo and the two-lane roundabout and not as absolute conclusions about the capacities of the two roundabout options (Engelsman, Uken 2007).

Mauro and Branco (2010) found that the capacities of turbo roundabouts' secondary entries were higher than the roundabout capacities when the traffic flow within the inner lane of the circle is high and the traffic flow within the outer lane of the circle is within the low to lower-middle range. In contrast, the capacities of the main entries to roundabouts are always higher than the capacities of the main entries to turbo roundabouts.

Tollazzi *et al.* (2011a) conducted a comparative analysis of capacities of the "standard", turbo, and flower roundabout, using a micro-simulation software PTV Vissim (Fig. 11). The right-of-way conflicting movements

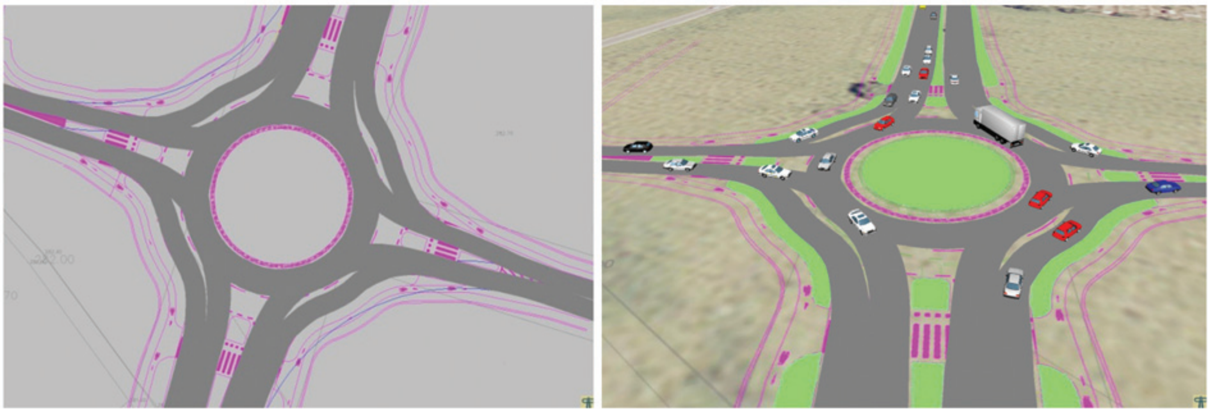

Fig. 11. The mathematical model and 3D simulation of the flower roundabout with PTV Vissim 5.20 (designed by APPIA Ltd. Ljubljana)

in Vissim were modelled using so called "Priority Rules", which are rather unique in the software industry. Instead of testing and calibrating the positions and parameters (min. gap time, min. headway) for a flower roundabout, it was decided to use the standard parameters which have been proved and tested for Slovenian conditions

Congestions and queue lengths were compared for four variants of traffic loads (750, 1000, 1250 and 1500 vehicles in the main traffic direction in the peak hour) and for three variants of right-turners (40%, 60% and 80% right-turners on the main traffic direction). All the scenarios presume that the minor stream accounts for 10% of the main traffic stream (Fig. 12).

The results of the micro simulation show that there are insignificant differences between the "standard" two-lane, turbo and flower roundabout at a low traffic loads. Congestions and queue lengths are approximately the same. At higher traffic loads, the differences occurred in favour of the flower roundabout, when the percentage of right-hand turners approached 60% of the total value of vehicles in the main traffic direction (Fig. 13).

Compared to the "standard" two-lane and turbo roundabouts, the flower roundabout shows its advantages, when the greater part of the traffic on the main direction, is in the direction of right-hand turners. Delays in the scenario "60%" and loads of "1250" are 20.02 s for flower roundabout (Level of Service – LOS = C), for "standard" two-lane are 40.20 s (LOS = D), and for turbo roundabout 66.40 s (LOS = D). The delay time represents the average delay time per vehicle at the intersection. It includes the stop time (traffic control, give-way) and time lost due to acceleration and deceleration of a vehicle.

The flower roundabout "burns-out" at the moment when the one-lane roundabout capacity is exceeded.

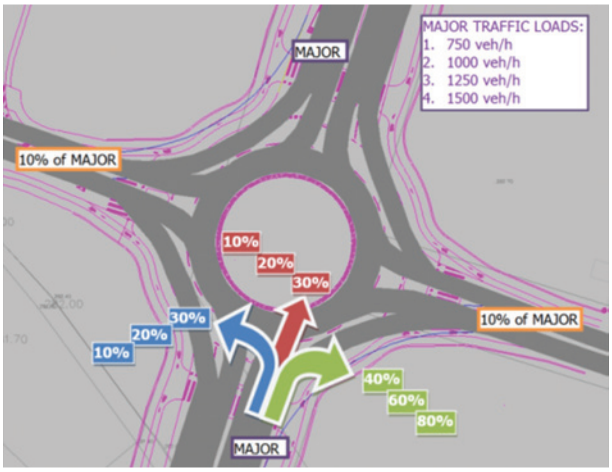

Fig. 12. Traffic distribution on major and minor legs for different scenarios; the distribution on North leg is symmetric to South leg (designed by APPIA Ltd. Ljubljana)

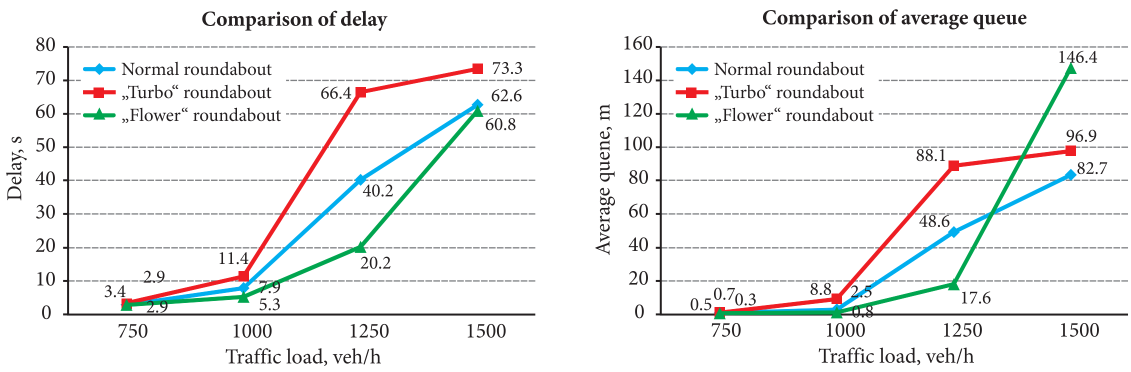

Fig. 13. Scenario with 60% of right-hand turners (designed by APPIA Ltd. Ljubljana)

4. Conclusions

1. Nowadays, a growing number of studies, as presented in scientific and professional literature, point out the poor traffic safety characteristics of "standard" two-lane roundabouts, and lower capacity than was expected. For this reason, many countries are looking for a solution as to what to within do within these existing roundabouts, in order to improve the levels of traffic safety and capacity.

2. The problem of low traffic safety within the "standard" two-lane roundabouts has been resolved in different ways in different countries, however the solution, whereby the number of conflict points is diminished has proved to be the most successful. The roundabout with the spiral course of the circulatory carriageway (in short: "turbo" roundabout) and the roundabout with "depressed" lanes for right turning (in short: "flower" roundabout) are types of roundabouts, that significantly diminish the number of conflict points. This paper illustrates these two relatively new alternative types of roundabouts, and their comparisons from the design, traffic-safety and capacity points of view.

3. From the designing point of view, the flower roundabout has an advantage over the turbo roundabout, as the former is easier to design. Probably the best characteristic of the flower roundabout is that it is implemented within the existing "standard" two-lane roundabout without any moving of (unlike the turbo roundabout) the outer road curbs of the circulatory carriageway, splitter islands, lighting poles.

4. When considering the traffic-safety, the flower roundabout has a slight advantage, as it does not contain any crossing conflict points, whilst there are also less merging and diverging conflict points.

5. When considering the capacity, the turbo roundabout has an advantage over the flower roundabout, as there are different types of turbo roundabouts for different directions of the prevailing traffic flows. The flower roundabout has an advantage only when the primary and secondary traffic directions have similar traffic loads and when there are many right-hand turners.

6. Both, the turbo and the flower roundabouts have their advantages and deficiencies, which makes sense as these are two alternative types of roundabouts intended for solving different problems.

7. In the near future, further development of roundabouts, mostly the developing of alternative types of roundabouts, intended for solving specific problems, will certainly present a challenge for this branch of science.

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